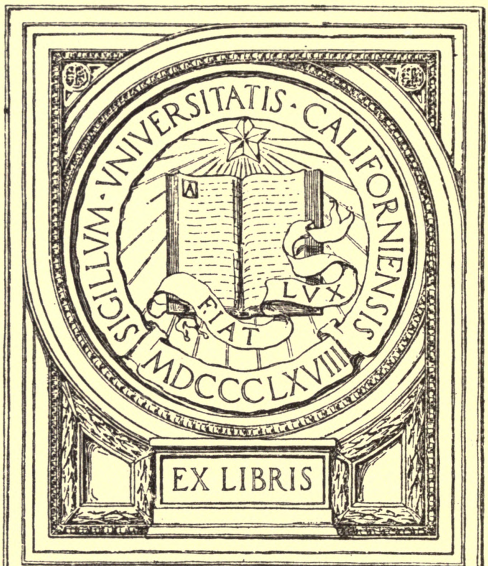
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THE ELECTRICAL CONTRACTOR

THE ELECTRICAL CONTRACTOR

PRINCIPLES OF COST-KEEPING AND ESTIMATING, WIRING AND ILLUMINATION CALCULATIONS AND OTHER TECHNICAL PROBLEMS OF THE BUSINESS

BY

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PREFACE

Only a few years ago the electrical contractor was an individual mechanic. The period of evolution to the organized business of today has been too short to permit of much standardization in systems of methods of handling work, and many men are suffering today the costly consequences. The need of better methods in both the commercial and technical phases is evident to anyone who comes in contact with the average contractor's organization and work.

In the hope that the essentials of the writer's system, developed during the past twenty years, and the technical data accumulated in connection therewith, may be of assistance to other contractors, the author has ventured to publish this material in book form. Much of the material has already appeared in the *Electrical World*.

L. W. M., Jr.

Philadelphia, Pa.
February, 1916.

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THE ELECTRICAL CONTRACTOR

CHAPTER I

PROFITS AND OVERHEAD EXPENSE

Profits

The two primary requisites for achieving success in the conduct of an electrical-contracting business are a knowledge of business principles and methods and a knowledge of electrical construction and the related engineering problems. Each of these factors is of equal importance, and real success in the electrical-contracting business cannot be obtained if either of these two factors be lacking.

Of primary importance to every contractor and every business man is the subject of profits. Every man in business desires to make a profit, but many have only a vague idea of the meaning of the word. To illustrate what is meant by the word "profit" take the case of a corporation. It has not made a profit on its year's business unless the amount of money received or assurable of collection without cost within a reasonable length of time exceeds the amount of money expended during the year. The amount of money expended by a corporation doing, for example, an electrical-contracting business includes not only the amount paid for labor and material actually used on its jobs but all amounts

paid for labor and material whether chargeable to any particular job or not. In other words, the material item should embrace the cost of engines and dynamos as well as ink and pencils, and the labor item should include not only the pay of the journeymen and helpers but also the salaries of the president and other officers.

If a corporation makes a profit on its year's business only under the conditions outlined, an individual or a group of individuals can make a profit only under the same conditions. The error which many persons who do a small business make is that they fail to include in the amount of money expended for labor during the year a salary for themselves. This should be equal to the sum that they would have to pay a person or persons for doing their work and producing the same results. Hence many persons doing a small business and neglecting to include a salary for themselves in the labor item do not make a profit. What appears to be profit may merely be a salary—perhaps meager at that.

Overhead Expense

There are two items which combined compose the cost of conducting an electrical-contracting business. These must be taken into consideration when figuring profits. The first item includes the cost of materials and labor actually used on jobs, such as engines, dynamos, panelboards, conduit, wire, etc., together with the salaries of the foreman, journeymen, helpers and apprentices. This item may be called, for convenience, shop or raw cost.

The second item includes the cost of materials and labor expended in securing a contract and in the execution of the job. It embraces the salaries of the officers,

bookkeeper, stenographer, bill clerk, draftsman, superintendent, etc., and the cost of rent, heat, light, taxes, insurance, stationery, postage, telephone and the like. This item is called manufacturer's expense or overhead charge. The shop or raw cost is always more or less an uncertain one and will be dwelt upon in detail in Chap. III, while overhead charges can be fairly well determined.

From a collection of data compiled by the National Electrical Contractors' Association on the costs of conducting an electrical-contracting business, it appears that the overhead expense of an electrical contractor lies between about 15 and 25 per cent. of his shop cost and that the average profit is figured at from 5 to 15 per cent. of the gross cost, depending upon the terms of the contract and the nature of the work.

The following outline gives a list of items which enter into a contractor's overhead expense:

Officers' salaries.
Salaries of office employees.
Salary of superintendent.
Estimating and selling expense (car fare, railroad fare, entertaining, etc.).
Stationery and sundries.
Postage, telephone, telegrams.
Depreciation of tools and furniture.
Insurance on property, furniture, stock, etc.
Liability and compensation insurance (if any).
Interest on investment.
Rent (if owner of building, taxes and depreciation).
Heat and light.
Repairs.
Attorneys' fees.
License fees (if any).
Association dues.
Miscellaneous.

This list may be said to include the items which almost every electrical contractor must include in figuring his overhead expense, but not necessarily all the items which he must include. Most contractors find it necessary to employ one or more automobiles in their business. If such is the case, the interest on the investment made for automobiles, the depreciation of the machines, the cost of garaging, the cost of operating and the cost of upkeep must be included in the overhead expense. Some contractors have other expenses, such as advertising, etc., that are properly considered as items in overhead expense. Hence, the list given is not complete but merely suggestive of the items which enter into a contractor's overhead expense.

Method of Computing and Applying Overhead Expense and Profit

From the preceding paragraphs it can readily be seen that any estimate for work which does not include, in addition to an estimate of shop cost, an item for manufacturer's expense is one that will result in a loss to the contractor.

The writer has found it more convenient and logical to compute the manufacturer's or overhead expense as a percentage of the shop cost, instead of as a percentage of the selling price. An estimate of overhead expense should be made at least once or twice a year and the percentage thus obtained added to the shop cost in all estimates made in the succeeding period to obtain the real cost. For example:

Shop cost:	
Pay of foremen, journeymen, helpers and apprentices	$ 80,000.00
Cost of material, engines, generators, conduit, wire, etc. .	200,000.00
Total shop cost..................................	$280,000.00

Overhead expense:	
Salaries of employers, co-partners or officers	$30,000.00
Salaries of office employees—bookkeepers, clerks, etc.	8,000.00
Salaries of superintendent, draftsman and engineer	10,000.00
Stationery, telephones, taxes, insurance, rent, etc	8,000.00
Total manufacturer's expense	$56,000.00

Manufacturer's or overhead expense as a percentage of shop cost equals $56,000 ÷ $280,000, or 20 per cent.

The real cost, therefore, of the year's business would be the shop cost, $280,000, plus the overhead expense of $56,000, or $336,000. Should the selling value of this work be $369,600, the contractor has made a profit of 10 per cent. on the investment made. Should the selling value, however, be only $334,992, he has lost 3 per cent. on his investment. A true estimate should, therefore, be made for any job as follows:

Shop cost	$10,000.00
Overhead expense at 20 per cent	2,000.00
Real cost	$12,000.00
Profit at 10 per cent	1,200.00
Amount of proposal	$13,200.00

Some contractors figure their overhead expense as a percentage of the selling price. If a contracotr's overhead expense is 20 per cent. of his selling price and he desires to make a profit of 10 per cent. on the selling price, he would not make it if he used the following method:

Shop cost	$1,500.00
20 per cent. overhead expense plus 10 per cent. profit	450.00
Amount of proposal	$1,950.00

To get the results desired—namely, 20 per cent. of selling price as overhead expense and 10 per cent. of

selling price as net profit—the estimate should be made in the following manner: If the shop cost is $1,500, this amount must represent 70 per cent. of the selling price, for the overhead expense is taken as 20 per cent. of the selling price and the profit is taken as 10 per cent. of the selling price. Hence the selling price should be ($1,500 ÷ 70) × 100, or $2,142. The overhead expense is 20 per cent. of $2,142, or $428, and the profit is 10 per cent. of $2,142, or $214. The sum of these two items, $642, subtracted from the selling price leaves the original shop cost of $1,500. Hence the previous method of estimating was in error by $2,142 – $1,950, or $192, as shown.

But the entire principle of applying overhead expense and profit as percentages of the selling price is wrong. Profit on a job is actually interest on an investment. The investment in the contractor's business is the sum of the shop cost and the overhead expense. Hence the profit should be computed as a percentage of this sum.

CHAPTER II

BOOKKEEPING

Different systems of bookkeeping are, of course, in use by electrical contractors. Some lack merit and others are of great usefulness. In designing any bookkeeping system it should be borne in mind that the simpler the system can be made the more satisfactory and efficient it will prove to be, provided that it gives all the information that the contractor should have about his business, such as overhead expense, cost of labor and materials for each individual piece of work and the gross profit of the same.

The system of bookkeeping to be described is the one employed by the firm with which the writer is connected. This system has been found very satisfactory and requires the minimum of labor.

Upon the receipt of an order for performing a certain piece of work, an order card (Fig. 1) is filled out and turned over to the credit department, where the rating, financial responsibility, etc., of the prospective customer is examined. If the result of this inquiry is satisfactory, the card is passed to the bookkeeping department, where the information contained on the card is entered in the contract ledger and the card filed in the order-card index file.

In the contract ledger, under the entry for the job, are charged all labor and material actually used on the job until the work is completed, no entry being made, however, for office expense.

FORM 5-S-2M 9-1-12-HEE

Name of Job

Description

Ordered by { verbally / written }

Price { Contract / T & M }

Terms of Payment

Name of { Architect / Engineer }

Send bill to

Name of Owner

Address of Owner

Location of Job

FORM 6-S-2M. 9-1-12-HEE

JOB CARD—KELLER-PIKE CO.

Job Name —————— Send Weekly Reports

Date —————— 19——

You are directed to install the work described below in the

Located at

Work should be started

Report for further instructions to

Date Completed —————— in charge.

Be careful to charge all labor, material and expenses to this job, using its name as above.

Description

When completed, enter date, sign and return this card to office. Repair men will enter on other side a description of any work done not covered above.

(OVER)

Fig. 1.—Order card and job card.

After the plans and specifications for the work are received the engineering department lays out the work, straightens out any discrepancies between the plans and the specifications, and secures any other information which may be necessary for the construction department to know before proceeding with the actual work. The plans and specifications are then turned over to the construction department, the superintendent of which fills out a job card (Fig. 1) with the name of the man who has been selected to be foreman of the work. The card then becomes the foreman's order for the work and is kept by him until the completion of the job. When the card is returned, the bookkeeping department knows the job has been completed and is ready for billing. This process is repeated in the case of any extra work which may be ordered by the customer, no foreman or workman being permitted to do any extra work on a contract until a job card for the same has been issued.

When the construction department starts a piece of work the superintendent fills out a stock-requisition sheet (Fig. 2). To guide him in ordering materials a copy of the estimate showing the estimated amounts of materials needed is also given him. Upon the receipt of the material at the job a second list is filled out on a special receipt form and receipted by the man in charge. After a job is completed, the surplus material is again listed and returned to the stock room, where the stock clerk enters the amount of material received on another special receipt form. Sheets such as those described are also filled out by the foreman in charge when material is transferred from one job to another and does not pass through the stock room.

PAGE

STOCK–REQUISITION SHEET Week Ending ____________

Note:-No material will be given without a requisition neatly and completely filled out.
Separate sheets must be made out for each job or extra, and in making out requisitions care must be taken that no writing or marks be made in right hand column.

Materials can not always be sent from our stockroom, but must be purchased. Therefore make requisitions as much ahead as possible of the date when materials are actually needed. In urgent cases where a telephone is available make requisition by phone, and send in the written sheet to confirm it. Try particularly to have all requisitions in at least as early as the day before materials are needed. Stockroom is open at 7.30 a.m.

KELLER-PIKE CO.

Date ____________ Date Wanted ____________

No. ____________ JOB NAME ____________ ____________ Signature

KELLER-PIKE CO. Gentlemen:-Please send the following material for use on job of which I have charge.

Ordered From ___ Order No.	Amount Filled From Supply House	Amount Filled From Stock	Amount Wanted	DESCRIPTION OF ARTICLES WANTED	Amount Brought Fwd.	Value from Stock	

FIG. 2.—Requisition sheet for construction materials.

By referring to the stock-requisition sheet (Fig. 2), it will be noticed that the amount of material desired is placed in the fourth column from the left, the amount of that material supplied from the stock room in the next column, and in the adjoining two columns the amount of that material furnished by any local supply house, together with the initials of the supply house and the contractor's order number to the supply house. All material going to a job is, therefore, entered, but only that portion of the materials supplied from the stock room is valued on the sheet, the amount being credited to the stock room and charged to the job. The material furnished by the supply house is billed by the supply house, whose account in the main ledger is credited and the amount charged in the contract ledger. The list of materials on the requisition sheets becomes, therefore, the bookkeeping department's "sheet of original entry," and these sheets are filed in an indexed loose-leaf ledger. The other material sheets mentioned are, on the other hand, simple memoranda for checking and receipts for materials.

To charge the stock room and credit a job on the return of materials, or to credit one job and charge another where materials have been transferred without passing through the stock room, a sheet similar to the requisition form, but of different color, is filled out in the office from the data contained on the other types of material sheets mentioned.

The bills for work done can be made out readily, the price being already established. In time-and-material work it is necessary for the billing clerk to refer to his contract ledger and copy down all material and labor items which have been charged to the work, giving the

DISTRIBUTION OF PAYROLL—WEEK ENDING ______________ 19____

NAME OF JOB	LABOR		EXTRAS		TOTAL	
TOTAL						

FIG. 3.—Form of payroll (itemized).

price at which the same were charged and noting whether the material was furnished from the stock room or from a supply house. This bill is made out in pencil and turned over to the construction department, by which it is examined and, if found correct, passed to the person pricing the material and labor.

The distribution of the labor on various jobs is made by the pay-roll clerk on a pay-roll sheet (Fig. 3), and the various jobs are charged and the cash account credited from this sheet.

CHAPTER III

COST-KEEPING

In order to obtain figures on costs it is necessary for a contractor to employ such cost-keeping systems as will enable him to know the unit costs of performing the various operations entering into the execution of any wiring contract. Unless a contractor does employ such cost-keeping methods, he can hardly be said to be engaged in business, for he is merely playing a game of chance with his entire investment and business future at stake.

In estimates for work there are two items of costs:

1. Costs of material.
2. Costs of labor.

No accurate figures for use in estimating the cost of the materials used on a job can be given, owing to the constant changes in price of most of these materials, such as wire, conduit, etc. On the other hand, while the rates paid for labor change, the changes are not of frequent occurrence and tables of labor costs can be worked out on the present rates for labor and any increase or decrease of rates can be taken care of by employing a percentage correction factor.

For engines, generators, motors, transformers, etc., it is always best to secure a bid on the apparatus direct from the manufacturer, especially if a reasonable time be given the contractor to prepare his estimate. It is preferable to have these quotations include the cost of

the apparatus delivered and erected in position, as well as the cost of foundations, templets, bolts, painting, etc. There are two reasons for this procedure: First, unless the percentage of profit is large, the contractor should not undertake the risk of accepting the apparatus f.o.b. point of delivery and taking the responsibility for any damage that may occur to the same before it is accepted by the owner. Second, the contractor is very likely to omit a number of items in estimating on such apparatus, and these items combined may amount to a considerable sum even though each is small itself.

Should, however, the job be a large one and the time for preparing an estimate be short, the approximate cost of the apparatus could be determined if the contractor has prepared curves of cost for the various sizes of such apparatus in the past and had frequently checked them. Such checking is absolutely necessary, as apparatus may vary considerably in price within comparatively short periods of time. Fig. 4 shows how these curves should be prepared.

Separate curves or tables should be prepared for directly connected and belted, single and four-valve or Corliss engines, also for directly connected and belted, direct-current and alternating-current generators of various types, as well as for motors of low, medium and high speeds, etc.

The same method could be followed for figuring the cost of certain other kinds of materials, although greater accuracy must be used in plotting some curves, for in some cases price differences of a few cents may be desired. This method is not intended to be pushed to its logical conclusion and made to apply to such items as switches, outlet boxes, receptacles and the like, the

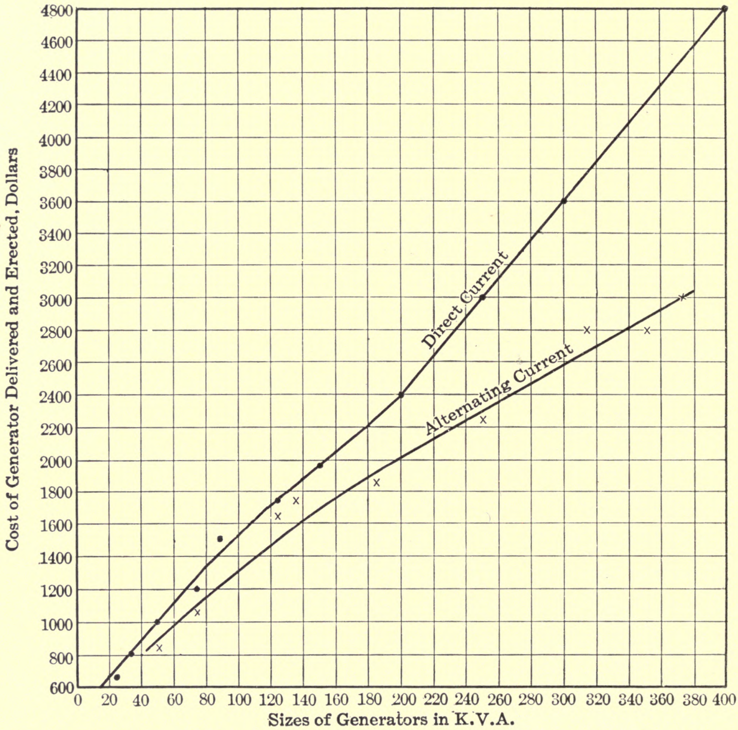

FIG. 4.—Curves showing the cost of directly connected engine-driven direct-current and alternating-current generators installed under ordinary conditions, the bases being furnished by engine contractor.

prices of which the contractor generally has at his finger tips, but it can be applied advantageously to such material as panel boxes, panelboards, doors and trim, annunciators, watchmen's clocks, etc.

For checking purposes or naming approximate costs to an owner for work being done on a time-and-material basis, this method can be used with the labor and material costs, combined as the data for these costs can be secured in the contract ledger from the completed jobs.

Take the following example, which is the cost for wiring a new residence of brick-and-joist construction by the concealed-conduit method. The service cables were run down the outside wall, the meter being installed in the basement. The system was three-wire, 110–220-volt, single-phase. The panelboards were of slate with 30-amp. type B switches, mounted in iron boxes, with wooden doors and trim. The switches were of Cutter manufacture and the receptacle of the flush wall type and of Pringle manufacture. The wire was rubber-covered and of the National Electrical Code standard.

The shop cost as shown by the contract ledger was $400.75, the cost items being as follows:

Materials	$254.36
Labor	136.74
Car fare, etc.	9.65
Shop cost	$400.75

The residence had 32 light outlets, 28 switch outlets and 20 receptacle outlets. The cost of a switch plus the labor of installing it was $1 and the cost of a receptacle plus the labor of installing it was $1.10.

If all outlets were light outlets, the shop cost would

have been approximately \$400.75 – [(28 × \$1) + (20 × \$1.10)] or \$350.75. Dividing \$350.75 by the total number of outlets, which is 80, \$4.38 is obtained. Hence \$4.38 is the cost of wiring per light outlet. The cost of wiring a switch outlet is \$4.38 + \$1, or \$5.38, and the cost of wiring a receptacle outlet is \$4.38 + \$1.10, or \$5.48.

This method is fairly accurate for small-residence work, and any number of costs per outlet may be compiled to cover the various types of wiring construction, wiring systems, etc.

Tables I to XI,[1] inclusive, give data from which such curves can be plotted, or, if desired, the data may be retained in tabular form. Too much emphasis, however, cannot be laid on the advisability of preparing such tables and curves from one's own records.

[1] Figures in Tables I, II, III and V are the figures the electrical contractor would secure from his subcontractors. Tables IV, VI, VII, VIII, IX, X and XI include the contractor's overhead expense and profit.

Table I.—Cost of Engines and their Foundations Installed Ready for Steam-pipe Connections[1]

Horsepower rating	Cost per horsepower		
	Single	Tandem-compound	Four-valve
50–100	\$16.00		
100–200	15.00	\$26.00	\$25.00
300 and above	14.00	24.00	23.00

[1] Installed ready for steam-pipe connections under ordinary conditions. The figures given are based on data from the Ames Iron Works, Oswego, N. Y.

TABLE II.—COST OF DIRECTLY CONNECTED DIRECT-CURRENT AND ALTERNATING-CURRENT GENERATORS[1]

Direct-current		Alternating-current	
Rating, kw.	Cost per kw.	Rating, kva.	Cost per kva.
25	$25.00	50	$16.00
35	23.00	75	14.00
50	20.00	125	13.00
75	16.00	135	12.00
100	15.00	185	10.00
125	14.00	250	9.00
150	13.00	312	9.00
200	12.00	350	8.00
250	12.00	375 and above	8.00
300 and above	12.00		

[1] These prices are based on engine-driven generators installed under ordinary conditions, the sub-bases for the erection of the generators being furnished by the engine contractor. The values given are based on data obtained from the General Electric Company.

TABLE III.—COST OF SWITCHBOARDS, INCLUDING DYNAMO AND FEEDER PANELS, 220 VOLTS OR LESS[1]

Direct-current		Alternating-current	
Rating, kw.	Cost per kw.	Rating, kva.	Cost per kva.
25- 50	$5.00-$10.00	50-125	$4.00-$6.00
50-100	4.00- 8.00	125-350	3.00- 4.00
100 and above	3.00- 6.00	350 and above	2.00- 3.00

[1] The range of prices is due to variations in the grade of materials and workmanship, the number of instruments, switches, etc. These figures include the switchboards erected complete and ready for the connection of generator cables, power and light feeders, etc. The prices are based on data obtained from the Walker Electric Company, Philadelphia.

Table IV.—Cost of Dynamo Connections[1]

Direct-current			Alternating-current		
Rating, kw.	Lead-sheathed rubber insulation	Rubber-covered cable in conduit	Rating, kva.	Lead-sheathed rubber insulation	Rubber-covered cable in conduit
25– 50	$50.00–$150.00	$25.00–$125.00	50–125	$100.00–$300.00	$75.00–$275.00
50–100	75.00– 250.00	50.00– 225.00	125–350	200.00– 400.00	175.00– 375.00
100 and above	100.00– 350.00	75.00– 325.00	350 and above	300.00– 500.00	275.00– 475.00

[1] The average flat distance between dynamo and switchboard has been assumed as 25 ft.

Table V.—Costs per Horsepower of Motors and Necessary Rheostats and Controllers Erected[1]

Direct-current		Alternating-current	
Horsepower	Cost	Horsepower	Cost
1 – 3	$50.00	1 – 1½	$60.00
5 – 7½	40.00	1½– 2	50.00
7½– 10	30.00	2 – 3	40.00
10 – 15	25.00	3 – 7½	30.00
15 – 25	20.00	7½–10	25.00
25 – 50	18.00	10 –20	20.00
50 –100	15.00	20 –35	18.00
100 –250	13.00	35 –75	15.00
250 and above	12.00	100 and above	13.00

[1] Motors are assumed to be of standard speeds, voltage, etc., and to be erected on floor, cost of foundations not being included. The costs include delivery and erection ready for wiring connections and are based on data obtained from the General Electric Company.

Table VI.—Costs of Wiring and Connecting Motors, Including all Labor and Materials[1]

Horsepower	Porcelain	Molding	Conduit
1– 5	$7.50–$75.00	$10.00–$100.00	$15.00–$150.00
5–10	30.00–120.00	40.00– 170.00	60.00– 240.00
15–25	75.00–250.00	90.00– 300.00	150.00– 300.00
25–50	100.00–400.00	125.50– 500.00	200.00– 500.00
50 and over	150.00–500.00	200.00– 600.00	300.00– 600.00

[1] The range of figures is due first to structural difficulties, second to the type of motor panel desired, third to the voltage, and fourth to the circuit distance. The lower figures represent the minimum structural difficulties, with fused switches in an iron box and with starting device mounted exposed on wall to side of motor, 220-volt service and 50-ft. to 100-ft. circuit distance. The higher figures represent the maximum structural difficulties, motor panels with circuit-breakers, 110-volt service and 150-ft. to 300-ft. circuit distance. The figures do not include the cost of motors, rheostats and regulators.

Table VII.—Average Costs per Outlet for Wiring for Lamps in New Buildings[1]

Outlets	Concealed porcelain	Exposed		Concealed conduit
		Wood molding	Metal molding	
Light	$4.00–$8.00	$5.00–$10.00	$8.00–$16.00	$7.00–$14.00
Switch	5.00–10.00	6.00– 12.00	9.00– 18.00	8.00– 16.00
Wall receptacle	5.00–10.00	6.00– 12.00	9.00– 18.00	8.00– 16.00
Floor receptacle	7.00–14.00	8.00– 16.00	11.00– 22.00	10.00– 20.00
Fan	6.00–12.00	7.00– 14.00	10.00– 20.00	9.00– 18.00
Iron	9.00–18.00	10.00– 20.00	13.00– 26.00	12.00– 24.00
Electric heater	7.00–14.00	8.00– 16.00	11.00– 22.00	10.00– 20.00
Vacuum control switch[2]	12.00–24.00	13.00– 26.00	16.00– 32.00	15.00– 30.00

[1] For use where the total cost of the work is about $2,000. For residences the lower figures should be used. For public buildings, such as banks, office buildings, churches and the like, a figure midway between the range of figures given should be used. Where best grade of material and workmanship is required the higher figures should be used. Prices do not include costs of fixtures or appliances, but do include switches and receptacles. For wiring old buildings where porcelain work and conduit work is concealed the figures given should at least be doubled. If porcelain or conduit work is to be installed exposed in either old or new buildings, the figures should be increased at least 25 per cent., the difference of cost depending upon the purpose for which the building is or was designed.

[2] Includes automatic starter at motor.

TABLE VIII.—AVERAGE COSTS FOR SIGNAL SYSTEMS RUN CONCEALED IN NEW BUILDINGS[1]

Bell wiring	Costs per outlet (connected as one outlet)	
	Porcelain	Conduit
Per push-button and bell	$6.00	$12.00
Per drop on annunciator	4.00	8.00

[1] For work on old buildings the figures given above should be doubled. The cost of push-buttons, bells and annunciators is included.

TABLE IX.—AVERAGE COSTS OF PRIVATE TELEPHONES

	Porcelain	Conduit
Per desk telephone	$30–$50	$40–$60
Per wall telephone	25– 45	35– 55

TABLE X.—AVERAGE COSTS OF PUBLIC TELEPHONES IN NEW BUILDINGS, CONCEALED WORK[1]

	Conduit
Per outlet	$5.00–$15.00

[1] Cost of wires is not included since the electrical contractor very seldom does the wiring. The range of the figures is due to variations in the distances between outlets. Instruments are assumed to be furnished and installed by the telephone company.

TABLE XI.—COST OF INSTALLING MISCELLANEOUS WORK[1]

Apparatus	Porcelain	Conduit
Time clocks	$30.00–$45.00	$35.00–$50.00 per clock
Time stamps	65.00– 85.00	70.00– 90.00 per stamp
Fire alarms	20.00– 30.00	25.00–35.00 per alarm
Watchmen's stations	25.00– 35.00	30.00– 40.00 per station

[1] The range of the figures given above is due to differences in the grades of workmanship and materials. For old buildings the figures given should be increased from 25 to 50 per cent. These figures include the cost of apparatus as well as the cost of all conductors, conduits and labor.

	LABOR ½″ CONDT.	LABOR 2″ CONDT.	LABOR #14 D.W	LABOR 2/0 h.	LABOR OUTLET BOXES	LABOR FIX. SUP'P.	LABOR SW. BOXES	LABOR SWS.	LABOR PANEL BOXES	LABOR PANEL B'D.	LABOR DOOR & TRIM	LABOR METER B'D. & SW.	TOTAL LABOR
WEEK ENDING	½ C.	2 C.	14 D.	2/0 W.	LT.B.	F.S.	SW.B.	SW.	P.B.B.	P.B.	D.& T.	M.B.	

FIG. 5.—Unit cost sheet compiled by clerk.

It is essential for the contractor to know the unit costs of labor for performing the various operations entering into the execution of any wiring contract as the method previously described will not give this information.

The labor item in the electrical-contracting business is subject to changes due to variations in the price of labor resulting from increases or decreases of rates and to variations in the unit costs with the nature of the building construction. The latter variations may amount to 100 per cent. or more.

The cost of labor can be determined with a fair degree of accuracy for buildings of various types, such as those of brick-and-joist construction, structural-steel construction with terra-cotta or concrete floors, and reinforced-concrete construction, by the following method, which may be worked out as elaborately as necessary and made to cover not only the labor required for installing different sizes of conduit, wires, etc., but also the labor required for connecting various sizes of wires to switchboards, dynamos, lugs, etc.

When a contract is secured in which the unit price of labor for certain parts of the work is not accurately known to the contractor, this information being desired for future use, he should endeavor to obtain these data by having a sheet such as shown in Fig. 5 prepared for his pay-roll clerk. A copy of this sheet should be given to the foreman on the job with instructions to mark his time sheets according to the symbols for the labor items as shown in Fig. 5, the time sheet thus marked being shown in Fig. 6.

At the end of the week the pay-roll clerk inserts on his unit-cost sheet the amount of money expended during that week for the various labor items on the job

Form 8-W-5M 9-1-14 S. H. L.

TIME SHEET *Week ending* ________________ 19__

Notice — Pay Roll closes Wednesdays. Time not then reported, will not be paid until the following week. Hours: 8 to 12 A.M. 12.30 to 4.30 P.M.

KELLER-PIKE CO.

	Hours	DESCRIPTION OF WORK	EXPENSES
Thursday	8	1/2" C	
Friday	4	2" C	
	4	St. B.	
Saturday			
Monday			
Tuesday			
Wednesday			
Total	16	☞ Do Not Write in Space Below ☜ *Signature,* John Smith	

Job	Hrs.	Exp.	
American Iron Co.	16	—	Total —
			Exp. —

FIG. 6.—Time sheets showing symbols for labor items.

under way, the total of these items equaling the total pay-roll for that job. This process is carried on until the completion of the work, at which time the total labor for each item is ascertained. Dividing the total labor for installing a certain material by the total amount of the materials installed, as ascertained from the contract ledger, a unit price is obtained for installing that material.

It is very often desirable, however, to know what the unit price of labor is at the end of each week, especially if the job is some distance from the contractor's office and is visited by his superintendent only once or twice during the progress of the work. This can be accomplished by the use of material sheets (Fig. 7) issued to the foreman. Taking, for example, the report on conduit work, the foreman fills out the lines marked A, B, C and D for the first week, after which only the lines A, B and C are filled out.

The line A designates the job. The line D, which is filled out only when the first slip is issued, indicates the amount of conduit on the job at the time the foreman arrives, while the line B, which is filled in by the foreman every week, indicates the conduit received during that week. Now, the line C, which is filled out by the foreman every week, indicates the amount of conduit on hand at the end of the week. Hence, the sums of the amounts of materials entered on the lines B and D minus the amounts entered on C, that is, $B + D - C$, for the first week indicate the amounts of the different sizes of conduit installed during that week.

After the first week the sums of the amounts of conduit along the line D of the first week's report and along the line B of all subsequent weekly reports, minus the

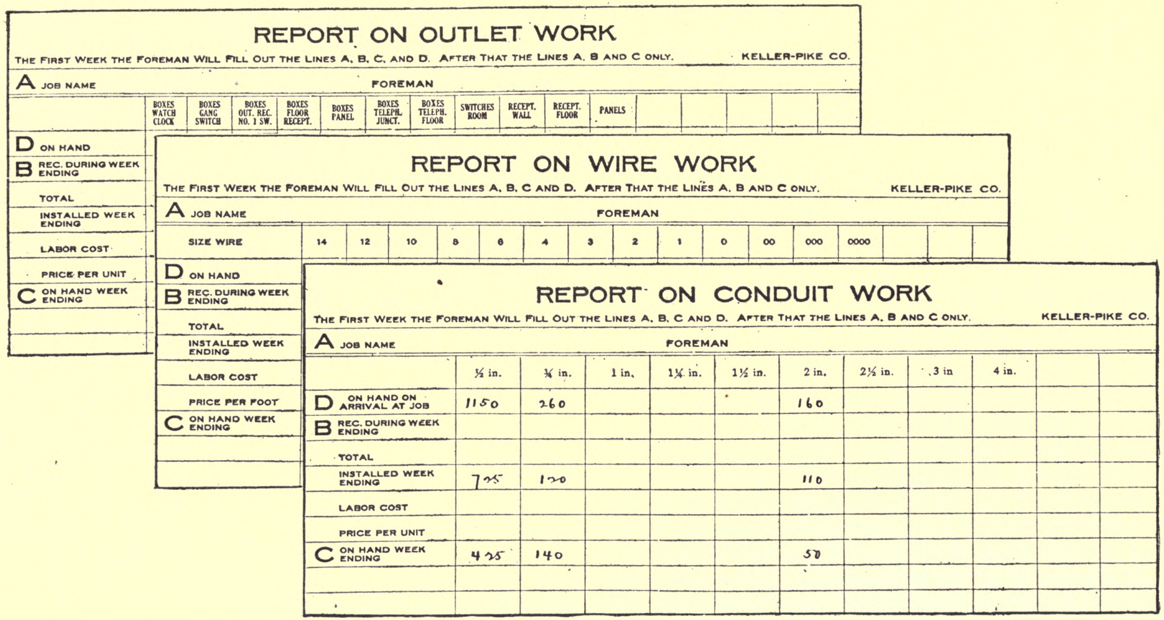

FIG. 7.—Weekly material reports to be filled in by the foreman.

amounts along the line *C* of the last report, indicate the amounts of the different sizes of conduit installed up to the time of the last report.

The labor costs from the weekly time sheet (Fig. 6) are then inserted along the line marked "labor cost," and the unit prices are accurately figured and placed along the line marked "price per unit." If the price per unit for any item is higher than the estimated price, the head of the construction department indicates this by placing a red cross opposite the particular item to which he desires to call the attention of the superintendent. The latter immediately investigates the matter, reporting on any possible causes for the increased costs and on the possibility of reducing the unit price.

This same process is carried out for wire work and outlet work. In the usual installation these items of conduit work, wire work and outlet work are by far the largest portion of the labor item, so that the work on signal systems, bells, etc., can be neglected. Otherwise the cost involved for ascertaining unit prices on the minor work would far overbalance the benefits of knowing these particular labor costs.

In Tables XII to XXIX as obtained by the above method are given the unit costs of labor. The data, however, cannot be considered general in their applications, for conditions vary widely in the electrical contracting field. Every contractor should make his own tables and curves, utilizing his records for the purpose. In all the following tables it is assumed that the rates for labor are 55 cts. per hour for foremen, 45 cts. per hour for wiremen, and 25 cts. per hour for helpers. All figures given include an allowance for what has been

found to be necessary supervision by the foreman in the class of work under consideration.

Table XII.—Cost per Kilowatt for Erecting Belted Generators

Size in kw.	Normal condition	Easy	Difficult	Cost of painting
1 - 5	$1.00	$0.75	$1.50	$0.60
5 -12½	1.00	0.75	1.50	0.60
12½-25	1.00	0.75	1.50	0.50
25 -50	1.00	0.75	1.50	0.40
75	0.80	0.60	1.25	0.30
100	0.75	0.60	1.20	0.25
150	0.60	0.50	0.90	0.20
200	0.50	0.40	0.80	0.18
300	0.40	0.30	0.60	0.15
500	0.30	0.20	0.50	0.12

Table XIII.—Cost per Kilowatt of Foundations for Belted Generators[1]

Size in kw.	Normal condition	Easy	Difficult
1 - 5	$2.00	$1.50	$3.00-$4.00
5 -12½	2.50	2.00	3.75- 5.00
12½-25	2.00	1.50	3.00- 4.00
25 -50	1.50	1.00	2.25- 3.25
75	1.20	0.85	1.80- 2.80
100	1.00	0.75	1.50- 2.50
150	0.85	0.60	1.25- 2.25
200	0.75	0.60	1.00- 2.00
300	0.60	0.50	0.90- 1.80
500	0.50	0.40	0.75- 1.50

[1] The items under this heading include the cost of labor and materials, which is the usual method of estimating this class of work. The figures are based on the average cubical contents of foundations specified by generator makers. If the electrical contractor is to furnish the belt or belts, the labor for putting them in place should be included.

Table XIV.—Labor for Erecting Switchboard Panels

	Dynamo panel without sub-base	Dynamo panel with sub-base	Feeder panel without sub-base	Feeder panel with sub-base
Cost per panel.....	$10.00	$12.00	$12.00	$15.00

Table XV.—Labor per Lead for Connecting Switchboard and Dynamo Leads[1]

Size, B. & S.	Paper and lead	Rubber and lead	Rubber or slow-burning insulation
14–8	$0.33	$0.30	$0.21
6	0.45	0.41	0.28
5	0.55	0.50	0.33
4	0.66	0.60	0.40
3	0.80	0.72	0.49
2	0.87	0.79	0.53
1	0.92	0.84	0.56
0	1.00	0.90	0.60
00	1.04	0.94	0.63
000	1.08	0.98	0.65
0000	1.14	1.03	0.69
Circ. mils			
250,000	1.18	1.08	0.72
300,000–350,000	1.34	1.22	0.78
400,000–450,000	1.43	1.30	0.84
500,000–550,000	1.60	1.44	0.90
600,000–650,000	2.10	1.90	1.00
700,000–750,000	2.50	2.25	1.25
800,000–850,000	2.95	2.65	1.50
900,000–950,000	3.30	3.00	1.75
1,000,000	3.75	3.40	2.00

[1] These figures are the labor costs for soldering cables into lugs at the switchboard and generators, also for soldering light and power cables into lugs of switches on the switchboard. They include the cost of arranging the cables in a neat and workmanlike manner at these locations.

TABLE XVI.—LABOR COSTS (IN CENTS) PER FOOT OF CONDUIT WORK[1]

Size of conduit	Steel-terra-cotta construction				Concrete construction				Slow-burning construction			
	Exposed		Concealed		Exposed		Concealed		Exposed		Concealed	
	Small am't	Large am't	Small am't	Large am't	Small am't	Large am't	Small am't	Large am't	Small am't	Large am't	Small am't	Large am't
½	7	6	6	4	8	7	7	5	6	5	6	4
¾	8	7	7	5	9	8	8	6	7	6	7	5
1	9	8	8	6	10	9	9	7	8	7	8	6
1¼	10	9	9	7	11	10	10	8	9	8	9	7
1½	11	10	10	8	12	11	11	9	10	9	10	8
2	12	11	11	9	15	12	12	10	12	10	11	9
2½	15	12	12	10	20	15	15	12	15	12	12	10
3	20	15	15	12	25	20	20	15	20	15	15	12
3½	25	20	20	15	30	25	25	20	25	20	20	15
4	30	25	30	20	40	30	30	25	30	25	30	20

[1] The figures given in the table of costs for conduit work are for work in new buildings and include the labor cost of preparing for and running rigid conduit per foot, as well as the labor on junction boxes. If conduits are to be installed in old buildings, the cost figures would be considerably greater than those given in the table, the percentage of increase depending on the conditions. However, for concealed work in existing buildings flexible conduit (see Table XVII) is generally used in order to do as little tearing out as possible.

TABLE XVII.—FLEXIBLE-CONDUIT LABOR COSTS PER FOOT FOR CONCEALED WORK IN EXISTING BUILDINGS[1]

Size, inches	Slow-burning construction	Fire-proof construction
½	$0.08	$0.10
¾	0.09	0.11
1	0.10	0.12
1¼	0.12	0.15
1½	0.15	0.20
2	0.20	0.30
2½	0.30	0.40
3	0.40	0.50

[1] The figures include cost of preparing for and running. There is little difference in cost whether the amount is large or small.

TABLE XVIII.—COST PER FOOT OF FISHING CONDUITS AND PULLING WIRES[1]

Size	One wire per conduit	Two or more wires per conduit
B. & S.		
14	$0.005	$0.004
12	0.006	0.004
10	0.0065	0.005
8	0.0075	0.006
6	0.0085	0.0065
5	0.01	0.007
4	0.013	0.0075
3	0.016	0.008
2	0.023	0.013
1	0.025	0.016
0	0.03	0.02
00	0.04	0.023
000	0.045	0.025
0000	0.05	0.03
Circ. mil.		
250,000	0.055	0.04
300,000–350,000	0.065	0.045
400,000–450,000	0.075	0.055
500,000–550,000	0.08	0.065
600,000–650,000	0.09	0.075
700,000–750,000	0.09	0.085
800,000–850,000	0.10	0.09
900,000–950,000	0.11	0.09
1,000,000	0.12	0.10
1,250,000	0.12	0.10
1,500,000	0.12	0.10
1,750,000	0.12	0.10
2,000,000	0.12	0.10

[1] These figures are for large amounts of rigid or flexible conduit in either new or existing buildings. For small amounts the figures should be increased from 10 to 30 per cent.

Table XIX.—Labor Cost of Installing Panelboards and Boxes

Number of circuits	Boxes				Panels installed and connected	Doors and trim
	New buildings		Old buildings			
	Exposed	Concealed	Exposed	Concealed		
1- 6	$1.00	$1.00	$1.00	$2.00	$1.00	$0.40
8–10	1.25	1.25	1.25	2.25	1.50	0.50
10–14	1.50	1.50	1.50	2.50	2.00	0.60
16–20	2.00	2.00	2.00	3.00	3.00	0.75
24–30	2.50	2.50	2.50	4.00	4.00	1.00

Table XX.—Labor Cost of Installing and Connecting Motors[1]

Hp. of motor	Mounting		
	Floor	Ceiling	Wall
1 - 2	$1.00	$1.50	$1.50
3 - 5	3.00	4.50	3.50
7½–10	6.00	9.00	7.50
15	10.00	15.00	12.00
20	15.00	22.00	18.00
25	20.00	30.00	24.00
35	25.00	37.00	30.00
50	35.00	51.00	42.00
75	50.00	75.00	60.00
100	75.00	110.00	90.00
150	100.00	150.00	120.00
200	150.00	225.00	180.00

[1] Includes labor on supports.

Table XXI.—Cost of Labor for Installing and Connecting Switches and Receptacles

Single-pole switches........	$0.20	Door switches.............	$0.20
Double-pole switches......	0.25	Wall receptacles.........	0.20
Three-way switches........	0.30	Floor receptacles..........	0.30
Four-way switches.........	0.25		

TABLE XXII.—LABOR COST OF INSTALLING OUTLET BOXES AND SUPPORTS

Type of outlet	Old buildings		New buildings		
	Steel and terra-cotta	Slow-burning	Concrete	Steel and terra-cotta	Slow-burning
Light outlets..........	$0.35	$0.30	$0.30	$0.25	$0.20
Fixture supports.......	0.10	0.10	0.10	0.10	0.10
Switch boxes..........	0.35	0.30	0.30	0.25	0.20
Wall-receptacle boxes...	0.35	0.30	0.30	0.25	0.20
Floor-receptacle boxes..	0.50	0.45	0.60	0.40	0.30

TABLE XXIII.—LABOR COSTS FOR INSTALLING MOTOR-CONTROL APPARATUS

H.p. of motor	Switch and rheostat	Controlling panel complete, switch, rheostat, etc.
1 - 2	$0.75	$2.00
3 - 5	1.00	3.00
7½-10	2.00	4.00
15	2.50	5.00
20	3.00	6.00
25	3.50	7.00
35	4.50	9.00
50	6.00	11.00
75	8.00	13.00
100	10.00	15.00
150	12.00	17.00
200	15.00	20.00

Table XXIV.—Labor per Foot of Wire for Installing Concealed Knob-and-tube Work

Size of wire, B. & S.	New buildings	Old buildings
14	$0.01	$0.03
12	0.01	0.03
10	0.01	0.03
8	0.012	0.035
6	0.015	0.045
5	0.018	0.055
4	0.02	0.06
3	0.023	0.07
2	0.025	0.075
1	0.03	0.09
0	0.03	0.09
00	0.035	0.11
000	0.035	0.11
0000	0.04	0.12

Table XXV.—Labor per Foot of Wire for Installing Exposed Knob-and-tube Work[1]

Size of wires, B. & S.	Running wire after backboard or buttons are erected	Erecting backboard or buttons
14	$0.015	$0.02
12	0.015	0.02
10	0.015	0.02
8	0.017	0.025
6	0.02	0.03
5	0.02	0.035
4	0.023	0.04
3	0.025	0.045
2	0.03	0.05
1	0.035	0.06
0	0.035	0.07
00	0.04	0.08
000	0.045	0.09
0000	0.045	0.10

[1] When good knob-and-tube work is installed in new and old buildings the labor at outlets will be practically the same as given in Table XXII under the several headings, and the labor for switches and receptacles should be exactly the same as in Table XXI.

Table XXVI.—Labor Cost per Foot for Installing Molding

Wires		Wood molding	Metal molding
Number	Size, B. & S.		
2	14	$0.04	$0.08
2	12	0.05	0.08
2	10	0.06	0.08
2	8	0.07	
2	6	0.08	

[1] Metal molding is not made in sizes larger than for No. 10 wires, and wood molding is seldom used for wires larger than No. 6. The labor at outlets with molding is practically the same in the case of both wood and metal-molding construction. Tables similar to Tables XXI and XXII can hence be made.

Table XXVII.—Cost of Pole-line Construction

Labor item	Description	Cost
Shaving poles	25-ft. pole	$0.60–$1.20
	30-ft. pole	0.80– 1.60
	35-ft. pole	1.00– 2.00
	40-ft. pole	1.20– 2.40
	50-ft. pole	1.40– 2.80
Erecting wood poles	25-ft. pole	0.90– 2.70
	30-ft. pole	1.20– 3.60
	35-ft. pole	1.80– 5.40
	40-ft. pole	2.70– 8.10
	50-ft. pole	3.90–11.70
Erecting iron poles	25-ft. pole	2.00– 8.00
	30-ft. pole	3.00–12.00
	35-ft. pole	5.00–20.00
	40-ft. pole	8.00–32.00
	50-ft. pole	12.00–48.00
Digging holes	25-ft. pole	0.60– 3.00
	30-ft. pole	0.75– 3.75
	35-ft. pole	0.90– 4.50
	40-ft. pole	1.05– 5.25
	50-ft. pole	1.20– 6.00
Stepping poles	25-ft. pole	0.50– 1.00
	30-ft. pole	0.75– 1.50
	35-ft. pole	1.00– 2.00
	40-ft. pole	1.25– 2.50
	50-ft. pole	1.50– 3.00
Guying poles	25-ft. pole	3.00– 9.00
	30-ft. pole	4.00–12.00
	35-ft. pole	5.00–15.00
	40-ft. pole	6.00–18.00
	50-ft. pole	7.00–21.00
Erecting cross-arms, braces, pins and insulators	2-pin cross-arm	$0.50–$1.00
	3-pin cross-arm	0.60– 1.20
	4-pin cross-arm	0.70– 1.40
	6-pin cross-arm	0.90– 1.80
	8-pin cross-arm	1.10– 2.20

Table XXVII.—Cost of Pole-line Construction—(*Continued*)

Labor item	Description	Cost
Stringing wire, triple-braid, weatherproof, per 1,000 ft.	No. 8	$2.50–$5.00
	No. 6	2.60– 5.20
	No. 5	2.80– 5.60
	No. 4	3.10– 6.20
	No. 3	3.50– 7.00
	No. 2	4.00– 8.00
	No. 1	4.60– 9.20
	No. 0	5.20–10.40
	No. 00	6.00–12.00
	No. 000	6.90–13.80
	No. 0000	7.90–15.80

Table XXVIII.—Labor Costs per Foot for Laying Ducts

Item	Cost
Laying duct and cementing joint:	
Single-way	$0.03 –$0.06
Two-way	0.05 – 0.10
Three-way	0.08 – 0.16
Four-way	0.10 – 0.20
Six-way	0.14 – 0.28
Nine-way	0.20 – 0.40
Laying conduit or pipe:	
½-in. conduit	$0.03 –$0.05
¾-in. conduit	0.04 – 0.06
1 -in. conduit	0.05 – 0.07
1¼-in. conduit	0.06 – 0.08
1½-in. conduit	0.065– 0.09
2 -in. conduit	0.07 – 0.10
2½-in. conduit	0.08 – 0.12
3 -in. conduit	0.09 – 0.14
4 -in. conduit	0.12 – 0.18

Table XXIX.—Labor Costs for Pulling in and Splicing Cables

Size, B. & S. or circ. mil	Pulling cable, cost per ft.	Splicing cables, cost per splice
Single-conduit:		
No. 14	$0.02	$1.10
12	0.025	1.20
10	0.03	1.30
8	0.035	1.40
6	0.04	1.55
5	0.045	1.70
4	0.05	1.85
3	0.055	2.00
2	0.06	2.20
1	0.0625	2.40
0	0.065	2.60
00	0.0675	2.80
000	0.07	3.05
0000	0.0725	3.30
250,000	0.075	3.55
300,000	0.0775	3.80
350,000	0.08	4.10
400,000	0.085	4.40
450,000	0.09	4.70
500,000	0.095	5.00
550,000	0.10	5.30
600,000	0.105	5.60
650,000	0.11	5.90
700,000	0.115	6.20
750,000	0.12	6.50
800,000	0.125	6.80
850,000	0.13	7.10
900,000	0.14	7.40
950,000	0.15	7.70
1,000,000	0.16	8.00

TABLE XXIX.—LABOR COSTS FOR PULLING IN AND SPLICING CABLES. —(*Continued*)

Size, B. & S. or circ. mil		Pulling cable, cost per ft.	Splicing cables, cost per splice
Duplex:			
No.	14	$0.03	$1.55
	12	0.04	1.80
	10	0.045	1.95
	8	0.05	2.10
	6	0.06	2.30
	5	0.07	2.55
	4	0.08	2.80
	3	0.09	3.00
	2	0.09	3.30
	1	0.095	3.60
	0	0.10	3.90
	00	0.105	4.20
	000	0.11	4.65
	0000	0.115	5.00
	250,000	0.12	5.40
	300,000	0.125	5.80
	350,000	0.13	6.20
	400,000	0.135	6.60
	450,000	0.14	7.10
	500,000	0.15	8.00
Triplex:			
No.	14	$0.04	$2.20
	12	0.045	2.40
	10	0.05	2.60
	8	0.055	2.80
	6	0.065	3.10
	5	0.075	3.40
	4	0.09	3.70
	3	0.10	4.00
	2	0.11	4.40
	1	0.12	4.80
	0	0.13	5.20
	00	0.14	5.60
	000	0.15	6.10
	0000	0.16	6.60

The figures given for pulling cable do not include rodding or fishing of ducts, which varies from $0.005 to $0.03 per duct foot.

CHAPTER IV

ESTIMATES

If the items entering into architects' and engineers' specifications were always given in succession from point of supply to the outlets, the chances of the electrical contractor omitting items in his estimate would be considerably reduced. Whether or not the architects or engineers write their specification in that form, the contractor should prepare his estimate so.

If an engine is to be installed in the plant, the contractor's first items should be for engines, foundations, painting, etc. Next should come the item for generators. If these be belted machines, the belts could be included under this item. Then should come the dynamo cables installed and connected to the lugs of the dynamos and switchboard. This should be followed by the item of switchboards installed complete with instruments, circuit-breakers, etc. This would practically complete the plant unless a storage battery was to be installed. A miscellaneous item could be inserted either at this point or under the general expense item at the end of the estimate covering the tests and if necessary the water rheostat.

The estimate should then include the following items in the succession here given, the costs of both material and labor being entered:

Connection of power and light feeders to switchboard.
Flexible tubing, junction box, condulets, etc.
Power feeders, mains and submains.

Power panels, boxes, doors, trim and fuses.

Power branches.

Power outlets, such as switches, starters and the like, erected and connected, wiring between switches, starters, etc., and motors.

Motors and foundations, delivered, erected and connected.

This would complete the power portion of the estimate, and the lighting portion should follow, the items being taken in the order given below:

Light feeders, mains and submains.

Panelboards, panel boxes, doors, trim and fuses.

Branches.

Outlets.

Expenses, cartage, freight, car fare, railroad fare, loss of time, inspection fees, shanty, telephone, bond, insurance and miscellaneous.

The same method should be followed in making an estimate for telephone, telegraph, fire-alarm, watchman's-clock, time-clock, annunciation and similar systems.

An estimate for light branches according to this detail method would appear as shown in Fig. 8.

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Item	Labor and materials	Unit price		
Light branches......	400 ft. ½-in. conduit, loricated.....	$0.06	$24.00	
	200 ft. ¾-in. conduit, loricated.....	0.07	14.00	
	600 ft. No. 12 duplex, N.E.C.S.....	0.03	18.00	
	200 ft. No. 12 single, N.E.C.S.....	0.015	3.00	
	Labor, ½-in. conduit..............	0.08	32.00	
	Labor, ¾-in. conduit..............	0.09	18.00	
	Labor, No. 12 duplex..............	0.01	6.00	
	Labor, No. 12 single...............	0.08	1.60	
	Supports, etc....................	....	3.40	$120.00
Outlets............	20 light outlet boxes, T. & B......	0.20	4.00	
	Labor........................	0.30	6.00	
	20 studs or supports, T. & B......	0.15	3.00	
	Labor........................	0.20	4.00	
	5 switch boxes..................	0.25	1.25	
	Labor........................	0.30	1.50	
	5 switches, D.P., Cutter...........	0.80	4.00	
	Labor........................	0.30	1.50	
	Bushings, etc....................	....	5.00	30.25

FIG. 8.—Applying the detail method to branch circuits.

In making an estimate for the electrical equipment in say a large institution composed of several similar size buildings, the mains in a number of cases may be of the same size.

As time is generally an important feature, one must be prepared to save all unnecessary detail work, which can be done in the following manner without effecting the accuracy of an estimate. Take, for example, the item of mains in an estimate. If made in detail, it would be as shown in Fig. 9.

Page 2 Estimate No. 10,176

Item	Labor and materials	Unit price		
Light mains, three-wire	200 ft. 2-in. conduit, loricated	$0.20	$40.00	
	3 2-in. L's, loricated	0.30	0.90	
	3 2-in. couplings, loricated	0.10	0.30	
	1 2-in. condulet (three-wire)		2.00	
	600 ft. No. 0 D.B., N.E.C.S	0.15	90.00	
	Labor, conduit	0.25	50.00	
	Labor, wire	0.05	30.00	
	Supports, junction box, etc		9.00	$222.20

Fig. 9.—Applying the detail method to mains.

It will be noted that the total cost for running 200 ft. of main consisting of three No. 0 wires is $222.20, or $1.10 per foot. The contractor could prepare tables of unit prices for all items in an estimate, such as for two-wire to nine-wire service connections, two-wire to five-wire mains, two-wire and three-wire branches, etc., showing their cost for buildings of various types of construction. The disadvantage of this method, however, is that a change in price of materials diminishes the accuracy of the tables.

Underground Construction

In estimating on underground construction work, a logical method should likewise be used. The first item to be considered being the trench work. Under this heading the following items should be included:

Excavating.
Concreting.
Ducts and laying of same.
Metal bands, burlap, pitch, etc., for joints.
Cables and installing same.
Refilling.
Regrading and resodding.

The next item should be that of manholes. Under this heading the following items should be included:

Excavating.
Brick or concreting work.
Drains.
Cable racks.
Splicing of cables.
Manhole covers.
Refilling.

With the addition to the above of an expense item an estimate for the ordinary underground-construction job would be complete. This expense item in some cases is considerable, especially where underground work is installed in populated district, when the cost of a watchman, lanterns and refilling of same and boards for covering exposed trench work during the night must be included.

Pole-line Construction

The first heading should be that of poles (wood) and should include the following items:

Digging of holes.
Shaving of poles.
Stepping poles.
Poles and erection of same.
Refilling—and if in a city, repairs to pavement, curb, etc., must be included.

The next item should be that of wires. Under this heading, the following items should be included:

Cross-arms and braces including erection of same.
Pins and insulators.
Wire and stringing of same.

With the addition to the above of an expense item an estimate for the ordinary pole-construction job would be completed. In large work of this type numerous additional items would be met with, such as:

Lightning arrestors and grounding.
Anchor rods and guying.
Transformers.
Lamps, brackets and cross-suspension.

CHAPTER V

CALCULATING WIRE SIZES FOR DIRECT-CURRENT CIRCUITS

The subject of voltage drop is one to which many electrical contractors, architects and engineers give very little attention. It is for this reason that the subject of the calculation of resistances, voltage drops and necessary sizes of wires, etc., has been included by the writer. The information given on these subjects is by no means intended by the writer as a treatise on electric wiring, but rather as general information which it is hoped will be of some value to electrical contractors, architects, engineers and owners.

Some of the formulas with which the writer is acquainted as recommended for computing voltage drops are not applicable to all systems of wiring. In many cases it is found that contractors are almost helpless when it is necessary to compute the voltage drop in even a small-size job. As a result lamps in many installations do not burn at maximum efficiency owing to excessive voltage drops. It is with the hope of rendering the calculation of voltage drop comparatively easy that the following discussion of voltage drop in direct-current and alternating-current circuits is given.

There are two factors that should be considered in laying out any direct-current circuit. First, the heat loss, which depends upon the value of the current and the material and size of the wire, must be considered.

The amount of this loss in watts is equal to the product of the square of the current in amperes multiplied by the resistance of the conductor in ohms, or C^2R. This heat loss is very seldom computed, as the Underwriters' requirements are intended to keep this loss well within the limit of safety. The carrying capacities of the various sizes of wire, as specified in the National Electrical Code, are such as to keep the temperature rise within safe limits for the type of insulation employed.

A size of wire, therefore, should be figured that will meet the pressure requirement and at the same time meet the requirements of the code in regard to safe carrying capacities.

By Ohm's law the allowable resistance in any wire to meet the voltage-drop requirement can be found by dividing the permissible loss in volts by the current, $R = E/C$, the resistance being in ohms. For example, what should be the resistance of a wire in which a current of 100 amp. is flowing, to give a voltage drop of 5 volts?

$$R = 5 \div 100 = 0.05 \text{ ohm}$$

Suppose the distance to be 250 ft. Then the circuit distance, assuming it to be a two-wire system, is 500 ft. A size of wire is required which will have a resistance of 0.05 ohm for a 500-ft. length. The writer employs tables which give the resistance of all sizes of wire in lengths of from 10 ft. to 1,000 ft. at 10-ft. intervals. A sample table is given in Table XXX. Complete tables of the same or similar nature can be found in numerous handbooks, text-books and wire manufacturers' literature. When tables such as these are examined it will be found that the size of wire would be No. 0. Tables

as indicated should be made or obtained for all sizes of wire used in practice.

TABLE XXX.—RESISTANCE IN OHMS OF No. 0 B. & S. GAGE HARD-DRAWN WIRE AT DIFFERENT LENGTHS AT 70°F.

Feet	0	10	20	30	40	50	60	70	80	90
0	∞	0.00099	0.00199	0.00299	0.00399	0.00499	0.00598	0.00698	0.00798	0.00898
100	0.00998	0.01097	0.01197	0.01297	0.01397	0.01497	0.01596	0.01696	0.01796	0.01896
200	0.01996	0.02095	0.02195	0.02295	0.02395	0.02495	0.02594	0.02694	0.02794	0.02894
300	0.02994	0.03093	0.03193	0.03293	0.03393	0.03493	0.03592	0.03692	0.03792	0.03892
400	0.03992	0.04091	0.04191	0.04291	0.04391	0.04491	0.04590	0.04690	0.04790	0.04890
500	0.04990	0.05089	0.05189	0.05289	0.05389	0.05489	0.05588	0.05688	0.05788	0.05888

If such tables are not at hand, as in the case of work on a small job away from the office, one can obtain the size of wire required by remembering that 1,000 ft. of No. 10 B. & S. gage wire has a resistance of approximately 1 ohm at 68°F., and that an increase of three sizes in the gage number divides the resistance by approximately two, and *vice versa.* Thus the resistance of No. 7 wire is half that of the same length of No. 10 wire, and the resistance of No. 13 wire is double that of the same length of No. 10 wire.

Consecutive sizes of wire differ in resistance by approximately the cube root of 2 (about 1.25); that is, the resistance of a definite length of No. 11 wire is approximately equal to one and a quarter times the resistance of the same length of No. 10 wire, and the resistance of a definite length of No. 9 wire is approximately equal to the resistance of the same length of No. 10 wire divided by 1.25. For a difference in gage number of two, the corresponding factor is the cube root of 4, or 1.58. By keeping these figures in mind the resistance of any length of any size of wire can be determined with a fair degree of accuracy.

In a three-wire, direct-current balanced system no

current flows in the middle wire if a true balance exists. For such a system the size of the wires is determined as in a two-wire system, the middle wire being made as large as the outside ones for safety, although some engineers will permit the middle wire to be made smaller in size.

In a double-neutral main, the object of which is to permit the use of either a two-wire 110-volt D.-C. system or a three-wire 110–220-volt D.-C. system, the circular millage of the two outside wires should equal the circular millage of the middle wire. To secure this result a double-neutral main should be figured for loss in pressure as if it was a two-wire main carrying the required current at 110 volts.

The size thus obtained would be the size of the middle or double-neutral wire and each of the outside wires should have one-half of the circular mils of the neutral. For example, if A equals the circular mils of each wire, $2A$ would be the total circular millage of a two-wire main carrying current at 110 volts. In a three-wire double-neutral main the circular millage of each wire would be $\frac{A}{2} + A + \frac{A}{2} = 2A$.

In some charts[1] which the writer has seen this has not been adhered to and instead of the outside wires being half of the neutral wire according to circular mils, the outside wires have been made one-half of the neutral wire according to the carrying capacity in amperes of the neutral, as listed in the National Code.

This results in actual practice of an increased loss in pressure (volts) over a figured one and under some conditions might prove embarrassing to a contractor.

[1] National Electric Contractors Association Chart.

Other voltage drops must be taken into consideration in addition to that due to the resistance of the wire. Such are those at cut-outs, panelboards and switches. On main circuits an allowance of 0.1 volt for each connection should be made, while on branch circuits an allowance of 0.1 volt at all cut-outs and switches should be made.

In figuring the resistance and other drops in branch circuits the same method is employed for either direct

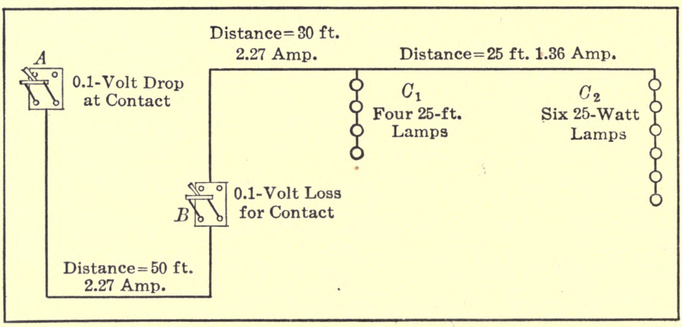

FIG. 10.

current or alternating current. The voltage drops on branch circuits should be figured separately for each length of circuit between outlets. For example, in the Fig. 10 is the panelboard and *B* a switch. C_1 and C_2 are lamp outlets. A two-wire system of distribution is assumed and the distances given are one-way distances only.

At C_1 there are four 25-watt lamps and at C_2 there are six 25-watt lamps. If a 110-volt system is installed, No. 14 wire would give a drop of 1.29 volts, as follows:

Resistance of No. 14 wire:

$$A \text{ to } B \text{ (100 ft.)} = 0.2567$$
$$B \text{ to } C_1 \text{ (60 ft.)} = 0.154$$
$$C_1 \text{ to } C_2 \text{ (50 ft.)} = 0.1283$$

By Ohm's law:

$$
\begin{aligned}
0.2567 \text{ ohm} \times 2.27 \text{ amp.} &= 0.58 \text{ volt}\\
0.154 \text{ ohm} \times 2.27 \text{ amp.} &= 0.34 \text{ volt}\\
0.120 \text{ ohm} \times 1.36 \text{ amp.} &= 0.17 \text{ volt}\\
\text{Total line resistance drop} &= 1.09 \text{ volts}\\
\text{Assumed loss at contact } A &= 0.1 \text{ volt}\\
\text{Assumed loss at contact } B &= 0.1 \text{ volt}\\
\text{Total drop } A \text{ to } C &= 1.29 \text{ volts}
\end{aligned}
$$

Size of Wire for Given Voltage Drop

In many cases it is necessary to know what size of wire will be required with a definite length of circuit to give a certain voltage drop with a certain current. Suppose, for example, that it is necessary to transmit electrical energy a distance of 205 ft. with a drop of 2.5 volts, the system being a direct-current 110-volt one, the current being 62 amp., and the 205 ft. being single distance.

For a drop of 2.5 volts and a current of 62 amp. the resistance should be 2.5 ÷ 62, or 0.0403 ohm. If tables are at hand showing the resistances required with different currents to give various voltage drops, this calcula-

Table XXXI.—Resistance in Ohms of Any Circuit Carrying a Given Number of Amperes with a Drop of 2.5 Volts

Current	0	1	2	3	4	5	6	7	8	9
0	∞	2.5000	1.2500	0.8333	0.6250	0.5000	0.4166	0.3571	0.3125	0.2778
10	0.2500	0.2272	0.2083	0.1923	0.1786	0.1667	0.1562	0.1470	0.1389	0.1316
20	0.1250	0.1190	0.1136	0.1087	0.1042	0.1000	0.0961	0.0962	0.0892	0.0862
30	0.0833	0.0806	0.0781	0.0757	0.0735	0.0714	0.0694	0.0676	0.0658	0.0641
40	0.0625	0.0609	0.0595	0.0581	0.0568	0.0555	0.0543	0.0532	0.0521	0.0510
50	0.0500	0.0490	0.0481	0.0472	0.0463	0.0454	0.0446	0.0438	0.0431	0.0424
60	0.0417	0.0410	0.0403	0.0397	0.0391	0.0384	0.0379	0.0373	0.0368	0.0362
70	0.0357	0.0352	0.0347	0.0342	0.0338	0.0333	0.0329	0.0325	0.0320	0.0316
80	0.0312	0.0309	0.0305	0.0301	0.0297	0.0294	0.0291	0.0287	0.0284	0.0281
90	0.0278	0.0275	0.0272	0.0269	0.0266	0.0263	0.026	0.0258	0.0255	0.0252

tion is unnecessary. Such tables, where used, can be made in the form shown in Table XXXI. This table gives resistance required for 2.5 volts drop for currents of 0 amp. to 99 amp. in steps of 1 amp. For higher currents one should remember that multiplying the current by 10 in the table multiplies the resistance values by 10. This table could have been applied in the case given by following the horizontal line marked 60 and the vertical line marked 2 (a total of 62 amp.) until they meet, at which point the resistance of 0.0403 ohm is obtained. After the ohmic resistance is found—namely, 0.0403 ohm—one can find the corresponding size of wire—namely, No. 0—by means of tables such as Table XXX, or by means of the relation existing between sizes of wire.

CHAPTER VI

CALCULATING WIRE SIZES FOR ALTERNATING-CURRENT CIRCUITS

In figuring the voltage drop in alternating-current circuits there are a number of voltage losses to be taken into consideration in addition to the resistance drop—namely, skin effect, inductance and capacity. The skin effect is very small unless the size of the wires is excessive. The other losses may be considerable. The writer has worked out multiplying factors which, when applied to the cross-section of wires as figured for resistance drop, give fairly accurate values for the total voltage drop in alternating-current circuits, provided that all the wires of the circuit are placed in the same conduit.

Before considering the subject of voltage drop, however, it is best to discuss the subject of power-factor. The power-factor of a generator, motor or complete wiring system is the ratio of the actual power required to the apparent power required, or it is the ratio of the power required as measured on a wattmeter to the product of the voltage and current as measured on a voltmeter and an ammeter. For example, a 20-hp. motor theoretically should consume at full load 20×746, or 14,920 watts. When the voltage and current at full load are actually measured, it may be found that their product is 18,660 watts, in which case the power-factor would be $14{,}920 \div 18{,}660$, or 80 per cent. In other

words, to obtain the volt-ampere intake of an alternating-current motor, divide the rating of the motor in watts by the power-factor in per cent. and multiply by 100. Divide this result by the voltage, and the result is the current required in amperes.

The power-factor of a circuit varies with the types of the loads connected, the values given in Table XXXII being what the United States Treasury Department gives as fair averages.

TABLE XXXII.—AVERAGE POWER-FACTORS FOR LIGHT AND POWER IN PER CENT.

Incandescent lamps	95
Arc lamps	70
Incandescent lamps and induction motors on same circuit	85
Induction motors, full load	80
Induction motors, constant-speed type, starting	60
Induction motors, elevator-type, starting	40

The writer has found that a good method for finding the sizes of wire required in an alternating-current system for a given voltage drop where all wires of the circuit are run in the same conduit is first to base the calculation on a two-wire direct-current system at the same voltage, including, of course, the power-factor in calculating the current. For example, consider the calculations for a two-phase, 220-volt, four-wire main feeding a 50-hp. motor. The length of the run is 200 ft., the voltage drop is to be 2.2 volts, or 1 per cent., and the power-factor is 80 per cent.

Rating of motor in watts = $50 \times 746 = 37{,}300$ watts.

Current without power-factor allowance = $37{,}300 \div 220 = 169.5$ amp.

Current with power-factor allowance = $(169.5 \div 80) \times 100 = 211.9$ amp.

The resistance that would be required in a two-wire

direct-current circuit to give a drop of 2.2 volts with a current of 211.9 amp. would be 2.2 ÷ 211.9 or 0.01 ohm.

A wire having a resistance of 0.01 ohm for 200 ft. of circuit or 400 ft. of wire would have a cross-sectional area of about 400,000 circ. mils.

The next step would be to find the size of wire based on a two-phase, four-wire system at the same voltage and having the same percentage of voltage drop. Table XXXIII shows the relative sizes of wires for all systems when carrying the same load at the same percentage of voltage drop.

Table XXXIII.—Relative Sizes of Wires for Same Load and Percentage Voltage Drop

Volts	No. of wires	No. of phases	Kind of energy	Cross-section of wires	Total cross-section	
110	2	....	D.C.	A; A	2A	
110	2	1	A.C.	A; A	2A	
220	2	....	D.C.	A/4; A/4	0.5A	
220	2	1	A.C.	A/4; A/4	0.5A	
110–220	3	....	D.C.	A/4; A/4; A/4	0.75A	
110	4	2	A.C.	A/2; A/2; A/2; A/2	2A	Plus increase for inductive reactance drop
110	3	2	A.C.	A/2; 1.4A/2; A/2	1.7A	
220	4	2	A.C.	A/8; A/8; A/8; A/8	0.5A	
220	3	2	A.C.	A/8; 1.4A/8; A/8	0.425A	
110	3	3	A.C.	A/2; A/2; A/2	1.5A	
220	3	3	A.C.	A/8; A/8; A/8	0.375A	

In the example given it was found that for a two-wire, direct-current, 220-volt, 50-hp. motor a conductor having a cross-section of 400,000 circ. mils would be required. For a two-phase, 220-volt, four-wire system the size of wires per leg would be one-half of this size, or 200,000 circ. mils. This cross-section of 200,000 circ. mils corresponds approximately to a No. 0000 B. & S. gage conductor. However, the cross-section must be increased to take care of the inductive reactance drop.

For estimating purposes the writer has prepared Table XXXIV of multiplying factors for use in computing sixty-cycle alternating-current circuits. Multiplying the cross-sectional area of a conductor as found above by the factor given in the table, the approximately correct size of rubber-covered wire will be obtained, provided that all wires of one circuit are run in the same conduit.

TABLE XXXIV.—MULTIPLYING FACTORS FOR SIXTY-CYCLE, TWO-PHASE AND THREE-PHASE ALTERNATING-CURRENT CIRCUITS[1]

Size of wire as calculated			Cross-section required in circ. mils	Nearest commercial size to that required
Gage No., B. & S.	Circ. mils	Multiplier		
14	4,107	1.00	4,107	14
12	6,530	1.00	6,530	12
10	10,380	1.00	10,380	10
8	16,510	1.00	16,510	8
6	26,250	1.00	26,250	6
5	33,100	1.01	33,431	5
4	41,740	1.02	42,575	4
3	52,630	1.03	54,209	3
2	66,370	1.06	70,352	1
1	83,690	1.09	91,222	0
0	105,500	1.12	118,160	00
00	133,100	1.21	161,051	000
000	167,800	1.32	221,496	225,000
0000	211,600	1.47	311,052	300,000
	250,000	1.62	405,000	400,000
	300,000	1.82	546,000	550,000
	350,000	2.06	721,000	750,000
	400,000	2.28	912,000	950,000
	450,000	2.53	1,138,500	1,200,000
	500,000	2.86	1,430,000	1,500,000

[1] These figures are based on rubber-covered wires run in conduit, all wires of one circuit being run in the same conduit. They should, hence, only be used where these conditions exist.

The size of wire which would have been required for a direct-current system was found to be of 200,000-circ. mil cross-section. The multiplier in this case as found in Table XXXIV is 1.47. Hence 200,000 × 1.47 = 294,000 circ. mil, the nearest commercial size being a 300,000-circ. mil wire.

Before deciding that a 300,000-circ. mil wire is the proper size to use, it should be checked for carrying capacity. Table XXXV gives the current required by alternating-current motors per horsepower per phase for different voltages, the effect of power-factor being taken into consideration. The values given have been found to be fair averages for all types of alternating-current motors.

Table XXXV.—Current Consumption of Alternating-current Motors[1]

Motor		Amperes per hp. per phase
Phases	Volts	
1	110	10.0
1	220	5.0
2	110	5.0
2	220	2.5
3	110	5.6
3	220	2.8

[1] When starting without load the currents given in the table should be multiplied by 1.4, and when starting at full load the values should be multiplied by 1.8.

It was found that a 300,000-circ. mil wire was the proper size for taking care of the voltage drop. The starting currents are:

$$(50 \times 2.5) \times 1.4 = 175 \text{ at no load}$$
$$(50 \times 2.5) \times 1.8 = 225 \text{ at full load}$$

In both cases the current is below the allowable carrying capacity of a 300,000-circ. mil cable, namely, 275 amp. Hence it is safe to use cables of this cross-section.

Calculation of Voltage Drop in Overhead Lines

In dealing with overhead-construction problems it must be remembered that the line drop is due to two factors—first, to ohmic resistance, and second, to the reactance of the line caused by self-induction. The current which will flow under such conditions is expressed by the formula:

$$I = \frac{E}{\sqrt{R^2 + (2\pi f L)^2}}$$

In this formula I is the current in amperes, E the voltage drop, R the resistance of the circuit in ohms, f the frequency in cycles per second, and L the self-induction of the circuit expressed in henries.

The value of L—that is, the self-induction of the circuit—can be accurately and simply determined for the case of a circuit where the outgoing and returning wires are parallel and no iron is near. These conditions exist in most overhead lines.

If l be the total wire length of a two-wire circuit in feet, d the distance between the axes of the two wires, and r the radius of the bare wires expressed in the same units as d, then the self-inductance L of the circuit in henries is expressed by the formula:

$$L = \frac{30.48l[0.5 + 4.6052 \log d/r]}{1,000,000,000}$$

The factor $2\pi fL$ is known as the reactance of the circuit.

To calculate the total voltage drop resulting from the reactance drop plus the resistance drop, the two must be combined at right angles as shown in Fig. 11—the hypotenuse of the triangle will then represent the impedance drop, that is, the total drop in voltage along the line.

For example, take a line 1,000 ft. long consisting of two No. 0 copper wires so strung that the distance be-

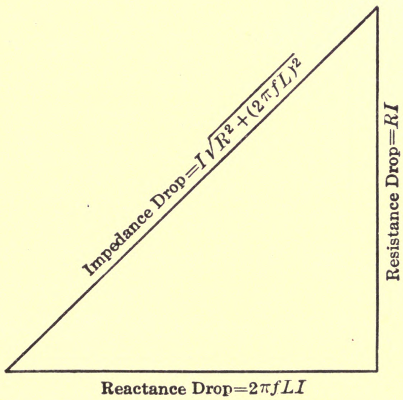

Fig. 11.

tween the centers of the wires is 12 in. What will be the voltage drop if the value of the alternating current is 10 amp. and its frequency is 125 cycles per second?

The inductance in henries is found by the formula previously given:

$$L = \frac{30.48 \times 2{,}000\,[0.5 + 4.6052 \log 12/0.19]}{1{,}000{,}000{,}000}$$

$$= 0.00056 \text{ henry.}$$

The resistance of 2,000 ft. of No. 0 wire is 0.1996 ohm. The impedance Z then becomes

$$\begin{aligned} Z &= \sqrt{R^2 + (2\pi f L)^2} \\ &= \sqrt{0.1996^2 + (2 \times 3.1416 \times 125 \times 0.00056)^2} \\ &= 0.48 \text{ ohm.} \end{aligned}$$

The voltage drop is $E = IZ = 10 \times 0.48$, or 4.8 volts. The voltage drop due to resistance, on the other hand, is only 10×0.1996, or 1.996 volts.

Suppose that the allowable drop in volts is specified in the case of a three-phase, three-wire transmission line with the wires placed at the corners of an equilateral triangle and that the size of the wires must be determined. Let 300 kw. be the energy to be transmitted, the frequency being sixty cycles per second, the pressure 1,200 volts, and the voltage drop 5 per cent., the wires being 24 in. apart between centers, and the length of the line (single-wire distance) 1,800 ft.

$$\text{Current per phase} = \frac{300{,}000}{1{,}200\sqrt{3}} = 145 \text{ amp.}$$

If the line were a single-phase circuit, the current would be 250 amp. To calculate the loss in the case of a three-phase feeder, consider each conductor as carrying 125 amp. (that is, one-half of the corresponding single-phase current) and complete the calculations as in the case of a single-phase line:

$$\text{Volts drop} = 0.05 \times 1{,}200 = 60 \text{ volts.}$$

$$\text{Double distance} = 3{,}600 \text{ ft.}$$

$$L = \frac{30.48l\,(0.5 + 4.6053 \log d/r)}{1{,}000{,}000{,}000}$$

At this point it is necessary to assume a value for r; that is, the radius of the conductor. Let 0.3 in. be assumed, this being the approximate radius of a 300,000-circ. mil cable. The log d/r does not change appreciably with slight changes in r owing to the relatively great value of d, and hence great accuracy is unnecessary.

$$L = \frac{30.48 \times 3{,}600(0.5 + 4.6052 \log 24/0.3)}{1{,}000{,}000{,}000} = 0.001$$

$$\text{Impedance} = \sqrt{R^2 + (2\pi f L)^2} =$$

$$\sqrt{0.126^2 + (2 \times 3.1416 \times 60 \times 0.001)^2} = 0.39 \text{ ohm.}$$

Now 0.126 ohm is the ohmic resistance of 3,600 ft. of 300,000-circ. mil cable.

$$I \times \sqrt{R^2 + (2\pi f L)^2} = E,$$

$$\text{or } 125 \text{ amp.} \times 0.39 = 48 \text{ volts.}$$

As 60 volts drop is permissible and a 300,000-circ. mil cable gives only 48 volts drop, a No. 0000 wire will be found to be approximately correct for a drop of 60 volts.

CHAPTER VII

ILLUMINATION CALCULATIONS

A great many contractors merely "guess at" the number of lamps required in the average installation. As a result, it often happens that either too few or too many are installed. In either event the customer is dissatisfied. In the first case he does not obtain the good illumination desired, while in the second case his lighting bill is excessive if all the lamps are used. The customer can, of course, change the size of the lighting units, but this should not be necessary.

Recently, however, there has been an improvement in this respect as the result of the educational campaigns that have been conducted by lamp and reflector manufacturers. Several comparatively easy and satisfactory methods have been devised for calculating the number of lamps required in the average installation.

Definition of Terms

In order to be able to solve illumination problems the contractor should make himself familiar with the following terms and their definitions:

The candlepower is the unit of light production and is defined as the light from a standard international candle burning under exact specifications. When a source of light is spoken of as being a 16 cp., it is meant that its intensity equals that of sixteen international

candles. In general, however, the candlepower of a source of light is not the same in all directions.

The foot-candle is the unit of intensity of illumination. As such it is the intensity of illumination produced by a 1-cp. source on a surface 1 ft. from the source and perpendicular to the direction of the light. The intensity of illumination of a unit surface perpendicular to the beam of light incident upon it is directly proportional to the candlepower of the source of light and inversely proportional to the square of the distance of the point from the source.

Calling I the intensity of illumination, in foot-candles, of a unit surface perpendicular to the rays of light incident upon it, c the candlepower of the source, and d the distance in feet from the surface to the source of light, the following formula is obtained: $I = c/d^2$.

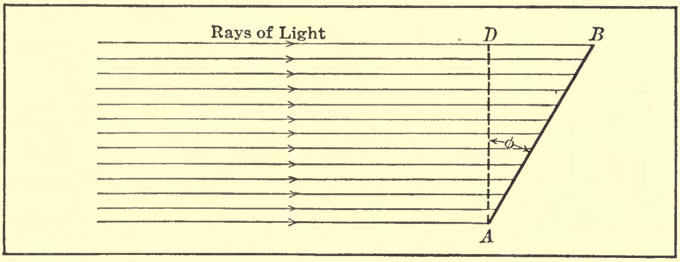

FIG. 12.—Intensity of illumination on an inclined surface.

Now, if the surface is not perpendicular to the beam of light incident upon it, as is the case with the surface represented by the dotted line AD in Fig. 12, but at an angle to it, such as the surface represented by AB, the intensity of illumination is reduced. A glance at the figure will show how this is true, for in the case of the surface AB the same number of light rays are dis-

tributed over the surface as over the smaller surface *AD*. Hence the intensity of illumination of the surface *AB* compared with the intensity on a surface at right angles to the rays of light is in the ratio of the length of the line *AD* divided by the length of the line *AB*. This relation may also be expressed by the formula in which the resulting intensity $I = c/d^2 \cos \varphi$, where the angle φ is the angle between the surface *AB* and a surface *AD* perpendicular to the rays of light incident upon *AB*. The expression $\cos \varphi$ is simply a mathematical way of indicating the ratio of the lengths $AD \div AB$.

These formulas, of course, assume that all rays of light incident upon the surface come directly from the one source considered, and that no reflection from walls, etc., takes place. It is also assumed that the surface under consideration is small enough and situated at a great enough distance from the source of light to justify the assumption that the rays of light incident upon it are practically parallel.

Candlepower Curves

Before considering the calculation of the number and spacing of lamps required for proper illumination of rooms devoted to various purposes it is best to study the distribution of light in the case of the common tungsten-filament lamp with and without an extensive type of reflector. Fig. 13 shows candlepower measurements taken of a 40-watt tungsten-filament lamp at various angles, both with (curve *B*) and without (curve *A*) an extensive-type Holophane reflector. The lamp is assumed to be at the center of the concentric circles in

such a position that the tip of the glass bulb points downward to what corresponds to the bottom edge of the page. Readings were taken at every 15 deg. in a plane passing through the glass stem supporting the filament of the lamp.

It will be noticed from curve *A* that a bare tungsten-filament lamp has its maximum candlepower intensity

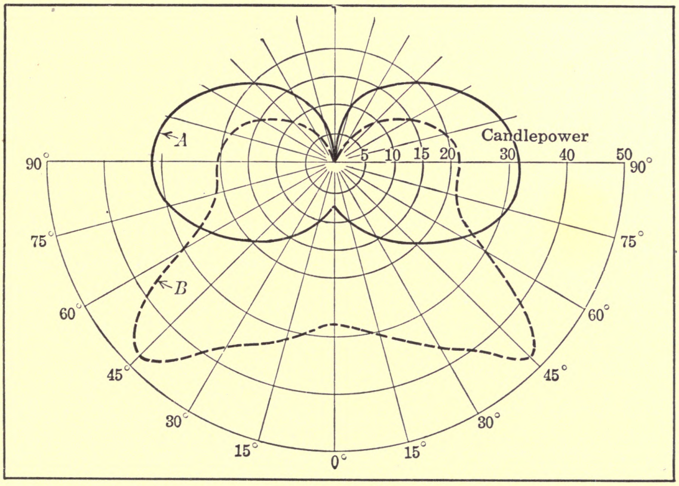

Fig. 13.—Candle-power curves for 40-watt tungsten type B lamp with and without extensive reflector.

in a horizontal direction. Directly beneath the lamp the candlepower is very low. The zero reading at the top of the lamp is, of course, due to the fact that the base of the lamp intercepts all light in that direction.

Curve *B* shows the distribution when an extensive type of Holophane reflector is used. The curve clearly shows that such a reflector causes a more desirable distribution of the rays of light from the lamp.

Intensity of Illumination

In Fig. 14 is given a diagram of a room illuminated by means of a 40-watt tungsten-filament lamp placed in the center of the ceiling and equipped with an extensive-type reflector. This diagram will be used to illustrate some of the principles heretofore discussed.

Let it be required to find the intensity of illumination on the unit areas *A* and *B* of the two tables indicated, the effect of reflection from all surfaces being neglected.

From the curve in Fig. 13 it is found that the vertically downward candlepower of the 40-watt lamp with an extensive type of reflector is 28 cp. Now the distance from the center of the lamp to the surface of the table at *A* is 8 ft., the surface of the table being assumed to be 2.5 ft. above the floor level. In most illumination problems it is generally assumed that the plane of illumination is at this distance above the floor, since the surfaces of tables, desks, etc., average about this height. The point *A* is assumed to be directly beneath the center of the incandescent lamp above, and hence the rays incident upon a small area at *A* will be practically perpendicular. Hence the following formula applies:

$$I = c/d^2 = 28 \div (8 \times 8) = 0.438 \text{ ft.-candle.}$$

Now, let it be required to find the intensity of illumination at a unit surface *B* on the table shown at the right in Fig. 14. In this case the point considered, *B*, is 8 ft. below the lamp and 8 ft. to the right. Hence the distance *y* is about 11.3 ft.

$$(\sqrt{8^2 + 8^2} = \sqrt{64 + 64} = \sqrt{128} = 11.3).$$

Referring to Fig. 13, it is seen that the candlepower of the lamp at an angle of 45 deg. below the horizontal is approximately 47 cp.

As the rays of light *y* strike *B* at an angle of 45 deg., the formula applies:

$$I = c/d^2 \cos \varphi = 47 \div 128 \cos \varphi$$
$$= (47 \div 128) \times 0.707 = 0.26 \text{ ft.-candle.}$$

In the same manner the intensity of illumination at any point in the room may be obtained.

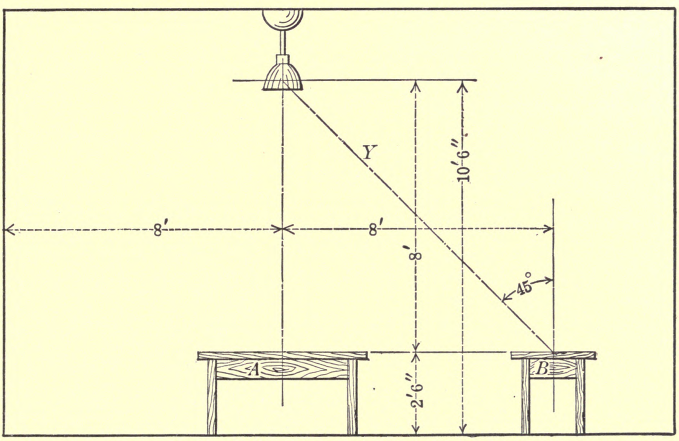

Fig. 14.—Illumination from ceiling fixture.

The intensity of illumination at any point in a room, however, depends also upon other factors which as yet have not been taken into consideration. The most important of these is the effect produced by the reflection of light from walls, ceilings, etc. In Table XXXVI are given the percentage correction factors which should be applied to results obtained as previously described in order to obtain a more accurate estimate of the inten-

sity of illumination at any point. This table and all others in this installment are based on data furnished by manufacturers of lamps, shades and reflectors. It is thus seen that the results previously obtained should be increased by from 0 to 80 per cent., depending upon the condition of the walls and ceilings.

Calculation of the Size of Units

A reversal of the process outlined will permit calculation of the size of lighting units to be installed in order to produce a certain intensity of illumination at given points.

Let it be assumed that an intensity of illumination of 0.3 ft.-candle is desired at A in Fig. 14, the room having ceiling and walls of medium color. From Table XXXVI it is seen that the effect of the reflection from ceilings and walls is to increase the average illumination about 40 per cent. Hence 0.3 ft.-candle respresents 140 per cent. of the intensity of illumination due to direct light from the lamp above, and the rays of the lamp must provide an intensity of illumination at A of 0.3 $\div$ 1.40 ft.-candles, or 0.214 ft.-candle. Since from the formula already given, $c = Id^2$, substituting,

$$C = 0.214 \times 64 = 13.7 \text{ cp.}$$

Table XXXVI.—Effect of Nature of Walls on Illumination

Color of ceiling	Color of walls	Increase of calculated illumination, per cent.
Very dark	Very dark	0
Medium	Very dark	15
Medium	Medium	40
Very light	Very dark	30
Very light	Medium	55
Very light	Very light	80

Table XXXVII.—Absorption of Light by Globes

Material	Percentage
Clear glass	5 to 12
Light sand-blasted glass	10 to 20
Albaster glass	10 to 30
Canary-colored glass	10 to 20
Opaline glass	15 to 40
Ground glass	20 to 30
Medium opalescent glass	20 to 40
Opal glass	25 to 60
Heavy opalescent glass	30 to 50
Milk glass	30 to 60
Signal-green glass	80 to 90
Light-green glass	30 to 40
Ruby glass	85 to 90
Cobalt-blue glass	90 to 95

Table XXXVIII.—Desirable Sizes of Squares for Spacing Outlets

	Ceiling height	Desirable length of sides of squares
Armories	12 ft. to 16 ft.	12 ft. to 16 ft.
Auditoriums	12 ft. to 16 ft.	12 ft. to 16 ft.
Public halls	Over 16 ft.	15 ft. to 26 ft.
Rinks	Over 16 ft.	15 ft. to 26 ft.
Stores	8 ft. to 11 ft.	8 ft. to 11 ft.
Stores	11 ft. to 15 ft.	10 ft. to 16 ft.
Stores	Over 15 ft.	14 ft. to 22 ft.
Offices with individual desk lamps	10 ft. to 20 ft.	12 ft. to 18 ft.
Offices without individual desk lamps	9 ft. to 12 ft.	7 ft. to 11 ft.
Offices without individual desk lamps	12 ft. to 16 ft.	9 ft. to 14 ft.
Offices without individual desk lamps	Over 16 ft.	11 ft. to 18 ft.

To find the size of lamp required it would be necessary to have curves of distribution of candlepower of numerous sizes of lamps equipped with various shades and reflectors at hand. The lamp and reflector or shade arrangement which shows a candlepower of 13.7 in a downward direction would be selected if other conditions were not to be taken into account.

However, in most illuminating problems it is necessary to fulfill specifications for intensity of illumination at more than one point in the room.

By applying the method outlined for various points in a room it is, of course, possible to find the combination of lamps and reflectors that will approximately fulfill the required conditions. This method of calculation, however, requires the plotting of curves showing the distribution of light for numerous sizes of lamps with various types of shades and reflectors. The method can be applied to rooms in which only one unit is required, but when extended to several rooms where more than one lighting unit is to be installed it becomes very laborious. Hence recourse is generally had to another method of calculating the size of lighting units required.

The Flux-of-light Method

The flux-of-light method is based upon the idea of luminous flux; that is, luminous energy proceeding from the source into space in all directions. Consider a lamp placed at the center of a sphere of unit radius so that one unit of area of this sphere may represent one unit of solid angle, then a lamp giving an intensity of illumination of 1 cp. in every direction will cause a certain amount of light or light flux to pass through a unit cone; that is, through an area of unit size on the surface of the sphere. This unit of light flux is called a lumen of light flux. In other words, the lumen is the quantity of light falling on 1 sq. ft. of a sphere of 1-ft. radius from a light source of 1-cp. intensity at the center of the sphere.

Table XXXIX.—Intensities of Illumination Found Suitable for Various Purposes

Installation	Foot-candles
Auditoriums	1 to 3
Theaters, general illumination	1 to 3
Churches, general illumination	2 to 3
Reading rooms	1 to 3
Residences, general illumination	1 to 2
Desk illumination	2 to 5
Postal service	2 to 5
Bookkeeping	3 to 5
Stores, general	2 to 5
Stores, clothing	4 to 7
Drafting	5 to 10
Engraving	5 to 10

Table XL.—Effective Lumens per Lamp[1]

Tungsten type C lamps. Watts per lamp

	100	200	300	400	500	750	1000
Effective lumens per lamp	650	1440	2360	3140	4140	6530	10000

Tungsten type B lamps. Watts per lamp

	25	40	60	100	150	250
Effective lumens per lamp	120	200	310	525	785	1360

[1] The table above shows the lumens effective for ordinary lighting with "Mazda" lamps and clear high-efficiency reflectors in rooms with average or dark walls and ceiling.

This method is generally applied in the shape of the following formula:

$$\text{Number of lamps} = \frac{S \times I}{\text{effective lumens per lamp}},$$

where S = the number of square feet floor area of the room and I = the required average intensity of illumination required in foot-candles. The term "effective lumens per lamp" refers to the total light flux from lamps that is available for illumination purposes.

To illustrate this method the following examples may be cited. A storeroom to be lighted measures 40 ft. by 100 ft. Considering the goods to be sold, it is decided,

after referring to the table of foot-candle intensities recommended for various classes of service (Table XXXIX), that 3 ft.-candles is sufficient for general illumination. Then the total lumens of light flux required would be three times the area in square feet, or $40 \times 100 \times 3$, which is equal to 12,000 lumens. By turning to Table XL of effective lumens for tungsten-filament lamps it is found that under ordinary conditions the number of 25-watt, type *B* lamps necessary would be $12{,}000 \div 120$, or 100. With 40-watt lamps $12{,}000 \div 200$, or 60, would be required.

These calculations are subject to correction for color of the wall and ceilings, types of reflectors used, etc. For example, if clear holophane reflectors are to be used in the store referred to above, and the walls and ceiling are of medium tint, the effective lumens from the lamps may be considered as 10 per cent. greater. If opaque reflectors were used instead of clear glass, the increase in illumination resulting from light ceilings and walls would be negligible, while if certain kinds of opal glass shades were used the influence of color of the ceiling and walls would be greater. It is somewhat difficult to estimate the difference in resulting illumination with different color decorations, and in residence work, where the wall paper may be changed from time to time, it is not wise to rely too much on reflection from surfaces.

For lighting by the use of indirect-lighting fixtures the writer has found the flux-of-light method to be very satisfactory when based on 0.4 watt per foot-candle for each square foot of horizontal surface to be illuminated.

To find the proper type of reflectors to be used curves like those shown in Fig. 15 may be employed. To find

the proper shade to be used, knowing the height of the unit above the floor level and the spacing between units, follow the vertical line representing the spacing between

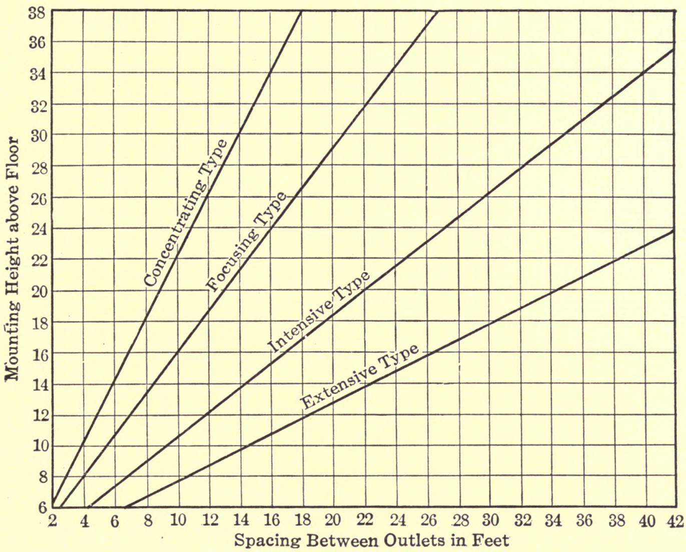

Fig. 15.—Curves for selecting type of reflector.

units until it intercepts the horizontal line marked "mounting height," and use the shade which is shown by the diagonal line to be nearest the point thus located.

CHAPTER VIII

GENERAL DATA

Such data as have been found necessary for the estimating and laying out of both large and small interior and underground electrical installation is included in this chapter. Data such as can usually be obtained from tables in the National Electric Code and from manufacturers' literature are, in general, omitted.

INTERIOR CONSTRUCTION

Conduit, Elbows and Couplings.—Dimensions referring to this material are omitted as the same can be obtained in the conduit manufacturers' catalogues.

Wire.—The diameters, weights and resistances for different sizes of wire can likewise be obtained in the wire manufacturers' catalogues.

TABLE XLI.—OUTSIDE DIAMETERS OF BUSHINGS AND LOCKNUTS

Size, in.	Outside diameter of bushings, in.	Outside diameter of locknuts, in.	Thickness of bushings, in.	Thickness of locknuts, in.
1/2	1	1 1/8	7/16	1/8
3/4	1 5/16	1 7/16	3/8	1/8
1	1 1/2	1 3/4	1/2	5/32
1 1/4	1 13/16	2 5/16	9/16	3/16
1 1/2	2 1/8	2 9/16	5/8	3/16
2	2 5/8	3 1/8	5/8	3/16
2 1/2	3 1/8	3 3/4	3/4	5/16
3	4	4 7/8	7/8	5/16
3 1/2	4 7/16	5 1/8	1	5/16
4	5	5 7/8	1	5/16

Locknuts and Bushings.—It is usually necessary to know the outside diameter of locknuts and bushings the diameters of which establish the spacing distances of conduits entering junction boxes, etc.

Panelboards.—The approximate sizes of panelboards are included as such sizes very often determine their location.

TABLE XLII.—APPROXIMATE SIZES OF PANELBOARDS[1]

Number of circuits	Two-wire mains, two-wire branches, dimensions, inches		Three-wire mains, two-wire branches, dimensions, inches, 110 volts
	110 volts	220 volts	
2	5.75 × 12	7 × 12	5.75 × 13.5
4	8.00 × 12	10 × 12	8.00 × 13.5
6	10.25 × 12	14 × 12	10.25 × 13.5
8	12.50 × 12	17 × 12	12.50 × 13.5
10	14.75 × 12	21 × 12	14.75 × 13.5
12	17.00 × 12	24 × 12	17.00 × 13.5
14	19.25 × 12	27 × 12	19.25 × 13.5
16	21.50 × 12	30 × 12	21.50 × 13.5
18	23.75 × 12	34 × 12	23.75 × 13.5
20	26.00 × 12	37 × 12	26.00 × 13.5
22	28.25 × 12	40 × 12	28.25 × 13.5
24	20.50 × 12	43 × 12	30.50 × 13.5
26	32.75 × 12	47 × 12	32.75 × 13.5
28	35.00 × 12	50 × 12	35.00 × 13.5
30	37.25 × 12	53 × 12	37.25 × 13.5

[1] For panels where N.E.C. inclosed fuses of 30 amp. and under are employed. No switches are assumed to be used on branch buses, and the main buses are assumed to be without switches or fuses.

Table XLIII.—Approximate Sizes of Panelboards, Dimensions in Inches[1]

Number of circuits	Two-wire mains, two-wire branches		Three-wire mains, two-wire branches, 110 volts
	110 volts	220 volts	
2	7 × 22	7 × 22	7 × 22
4	11 × 22	11 × 22	11 × 22
6	15 × 22	15 × 22	15 × 22
8	17 × 22	20 × 22	17 × 22
10	20 × 22	23 × 22	20 × 22
12	23 × 22	27 × 23	23 × 22
14	27 × 23	32 × 23	27 × 23
16	29 × 23	35 × 23	29 × 23
18	32 × 23	39 × 23	32 × 23
20	35 × 23	44 × 24	35 × 23
22	39 × 23	48 × 24	39 × 23
24	41 × 24	52 × 24	41 × 24
26	44 × 24	56 × 24	44 × 24
28	48 × 24	60 × 24	48 × 24
30	52 × 24	64 × 24	52 × 24

[1] For panels where fuses and switches of 30 amp. and under are employed for branches and where no fuses or switches are provided on the main buses.

Knife Switches.—

Table XLIV.—Average Overall Dimensions of N.E.C. Fused and Fuseless Switches, Front-connected[1]

	Size	Double-pole, inches	Three-pole, inches	Four-pole, inches	Five-pole, inches
Fuseless switches	....	H. W. D.	H. W. D.	H. W. D.	H. W. D.
	30	11 7 2 9/16	11 10 2 9/16	11 12 2 9/16	11 15 2 9/16
	60	13 8 2 7/8	13 11 2 7/8	13 14 2 7/8	13 17 2 7/8
	100	15 9 3 1/4	15 12 3 1/4	15 15 3 1/4	15 19 3 1/4
	200	19 10 4 5/16	19 13 4 5/16	19 17 4 5/16	19 21 4 5/16
Fused switches...	....	H. W. D.	H. W. D.	H. W. D.	H. W. D.
	30	11 7 2 13/16	11 10 2 13/16	11 12 2 13/16	11 15 2 13/16
	60	13 8 3 3/8	13 11 3 3/8	13 14 3 3/8	13 17 3 3/8
	100	17 9 4 1/2	17 12 4 1/2	17 15 4 1/2	17 19 4 1/2
	200	21 10 5	21 13 5	21 17 5	21 21 5

[1] Data furnished by the Walker Electric Company, Philadelphia.

From the above table the sizes of iron boxes for knife switches may be obtained.

General.—Such data as the carrying capacity of wires, the number of wires in a single conduit, the sizes of such conduits and so forth can be found in *Rules* 18 and 28, 1915 National Electrical Code, as issued by the National Board of Fire Underwriters.

Underground Construction

Excavation.—The average contractor sublets this portion of his work, the cost of which will average between 50 cts. and $2 per cubic yard depending upon the soil.

Concreting.—What has been said regarding excavation applies to this item likewise, the cost of which will average between $9 and $15 per cubic yard. For contractors' estimates on their own concrete work the following table giving the various amounts of concrete, sand and stone per cubic yard of rammed concrete in different proportions, will be found useful.

Table XLV.—Amounts of Cement, Sand and Stone Required per Cubic Yard of Rammed Concrete

Stone, mixtures 1 in. and under			Screened-out amounts		
Concrete	Sand	Stone	Concrete, bbls.	Sand, cu. yd.	Stone, cu. yd.
1	2.0	4	1.46	0.44	0.89
1	2.5	5	1.19	0.46	0.91
1	3.0	5	1.11	0.51	0.85
1	3.0	6	1.01	0.46	0.92
1	3.0	7	0.91	0.42	0.97
1	4.0	7	0.83	0.51	0.99
1	4.0	8	0.77	0.47	0.93

Brick Work in Manholes.—What has been said regarding the above items applies to this item likewise, the

cost of which will average between 75 cts. and $1.50 per cubic foot.

Vitrified Ducts.—

TABLE XLVI.—OUTSIDE DIMENSIONS OF VITRIFIED DUCTS

Type	Bore, round or square, in.	Outside dimensions, in.
Single-way	3½	5 × 5 × 18
Two-way	3½	4 × 9 × 24
Three-way	3½	5 × 13 × 24
Four-way	3½	9 × 9 × 24
Six-way	3½	9 × 13 × 36
Nine-way	3½	13 × 13 × 36
Nine-way	2	9 × 9 × 36

Telephone Cables.—The usual literature of wire manufactures does not give the outside diameters of paper-covered lead-encased telephone cables. The following table applies to type *G* lead-covered telephone cables as manufactured by the Western Electric Company.

TABLE XLVII

No. of pairs	Outside diameter, in.	No. of pairs	Outside diameter, in.
5	3/8	40	23/32
10	7/16	50	13/16
15	1/2	60	7/8
20	9/16	75	15/16
25	19/32	100	1 1/16
30	5/8	120	1 5/32
35	11/16	150	1 9/32
		200	1 17/32

Electric Light and Power Cables.—The usual literature of wire manufactures does not give the outside diameters of rubber-covered, lead-encased cables.

Single Conductor.—

TABLE XLVIII.—OUTSIDE DIAMETERS OF CABLES FOR 600 VOLTS PRESSURE OR LESS

Size	Thickness of rubber, in.	Thickness of lead, in.	Outside diameter	
			Solid, in.	Stranded, in.
14	3/64	3/64	0.28	0.30
12	3/64	3/64	0.30	0.31
10	3/64	3/64	0.33	0.34
8	3/64	3/64	0.35	0.38
6	1/16	1/16	0.47	0.47
5	1/16	1/16	0.50	0.50
4	1/16	1/16	0.52	0.52
3	1/16	1/16	0.53	0.55
2	1/16	1/16	0.56	0.58
1	5/64	1/16	0.63	0.66
0	5/64	1/16	. . . .	0.69
00	5/64	1/16	. . . .	0.73
000	5/64	1/16	. . . .	0.78
0000	5/64	1/16	. . . .	0.84
250 M	3/32	5/64	. . . .	0.95
300 M	3/32	5/64	. . . .	1.02
350 M	3/32	5/64	. . . .	1.08
400 M	3/32	5/64	. . . .	1.11
450 M	3/32	5/64	. . . .	1.19
500 M	3/32	5/64	. . . .	1.20
550 M	7/64	3/32	. . . .	1.33
600 M	7/64	3/32	. . . .	1.34
650 M	7/64	3/32	. . . .	1.38
700 M	7/64	3/32	. . . .	1.41
750 M	7/64	3/32	. . . .	1.44
800 M	7/64	3/32	. . . .	1.47
850 M	7/64	3/32	. . . .	1.50
900 M	7/64	3/32	. . . .	1.53
950 M	7/64	3/32	. . . .	1.56
1000 M	7/64	3/32	. . . .	1.59

Duplex Conductor.—

Table XLIX.—Outside Diameters of Cables for 600 Volts Pressure or Less

Size	Thickness of rubber, in.	Thickness of lead, in.	Outside diameter, stranded, in.
14	3/64	3/64	0.30 × 0.50
12	3/64	3/64	0.31 × 0.53
10	3/64	3/64	0.34 × 0.59
8	3/64	1/16	0.41 × 0.69
6	1/16	1/16	0.47 × 0.81
5	1/16	1/16	0.50 × 0.88
4	1/16	1/16	0.52 × 0.91
3	1/16	1/16	0.55 × 0.97
2	1/16	5/64	0.61 × 1.06
1	5/64	5/64	0.69 × 1.22
0	5/64	5/64	0.72 × 1.28
00	5/64	5/64	0.77 × 1.38
000	5/64	5/64	0.81 × 1.47
0000	5/64	5/64	0.88 × 1.59
250 M	3/32	3/32	0.95 × 1.64
300 M	3/32	3/32	1.02 × 1.88
350 M	3/32	3/32	1.08 × 2.00
400 M	3/32	3/32	1.11 × 2.06
450 M	3/32	3/32	1.19 × 2.22
500 M	3/32	3/32	1.20 × 2.24

Triplex Conductor.—

Size	Thickness of rubber, in.	Thickness of lead, in.	Outside diameter stranded, in.
14	3/64	1/16	0.59
12	3/64	1/16	0.63
10	3/64	1/16	0.70
8	3/64	1/16	0.77
6	1/16	5/64	0.94
5	1/16	5/64	1.00
4	1/16	5/64	1.03
3	1/16	5/64	1.09
2	1/16	5/64	1.13
1	5/64	3/32	1.19
0	5/64	3/32	1.28
00	5/64	3/32	1.38
000	5/64	3/32	1.50
0000	5/64	3/32	1.64

INDEX

A

B

C

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